Secretary's PTC Progress Report to the Congress--
~~Outline for Discussion by the Implementation Task Force~~

NOTE: The immediate task before the Working Group is preparation of its own report to the Administrator. Preparation of the report in a format suitable for use as a progress report to the Congress will assist FRA in meeting its statutory responsibilities. The Administrator will review the report to ensure that it represents Administration policy. The Office of the Secretary of Transportation, with review by the Office of Management and Budget, will have final approval of this report. FRA seeks assistance from the PTC Working Group in developing this report *and will clearly distinguish in the final Report to Congress any material approved by the RSAC from any material not approved by the RSAC*.

Table of Contents

Executive Summary in Front *(FRA will do**, Grady Cothen** - point of contact)*, then:

I. Introduction

This is a report of the Railroad Safety Advisory Committee (RSAC) to the Federal Railroad Administrator on the status and future of Positive Train Control (PTC) systems. The report was prepared by the RSAC PTC Working Group, which worked for over a year to gather facts, review options and deliberate on the best approach to encouraging rapid and successful deployment of PTC technology. The working group was comprised of representatives of freight and passenger railroads, labor organizations, industry equipment suppliers and State departments of transportation, assisted by Federal Railroad Administration (FRA) counsel and staff. The implementation of PTC systems is a broad and complex subject. As such the working group members were not able to agree on all issues related to deployment of PTC, although the group was able to advance ~~FRA's~~ understanding of the issues. In addition, the working group identified important actions that should be taken to create a favorable climate for introduction of PTC systems. The RSAC requests that the full text of this report be included in the Secretary of Transportation's forthcoming progress report to the Congress on PTC systems.

Since the early 1980's, the railroad industry has recognized the possibility of using data radio communications, emerging microprocessor-based systems, and other contemporary technologies to perform enhanced train control functions. In concept, this approach should make it possible to end most train-to-train collisions, enforce restrictions on train speed, and enhance protection for roadway workers–at a cost lower than would be expected using traditional approaches. Some in the industry have identified business benefits that might accrue from institution of such systems. All parties involved in the RSAC PTC process seek to define systems that are safety-effective, cost-effective, and interoperable as a railroad industry standard. These are the key elements in ensuring that promised benefits of the technology may soon be achieved in actual deployments.

Industry standards efforts and test programs have developed several variations of this concept, but railroads have not yet judged it technically and financially prudent to make large scale capital investments required to complete systems development and to deploy the technology on a broad scale. Meanwhile, the National Transportation Safety Board (NTSB) and the Federal Railroad Administration (FRA) have continued to urge that the potential safety benefits of PTC be realized at the earliest possible date.

One of the difficulties in realizing the benefits of PTC systems is the number of entities that need to cooperate to make it happen. With the goal of encouraging collaboration between the public and private sectors and gathering information to enlighten public policy, Administrator Molitoris requested the RSAC to investigate this issue and recommend appropriate action. On September 30, 1997 the RSAC accepted three PTC-related tasks. In summary, the tasks were to:

2 Prepare a descriptive report to facilitate understanding of current PTC technologies, definitions, and capabilities (Task 97-4)

3 Complete analysis and prepare recommendations to address any remaining issues regarding the feasibility of implementing fully integrated PTC systems, evaluate factors that may guide decisions on how PTC could yield optimum benefits in relation to costs, and determine the timetable over which such systems could be deployed–taking into account the need to first complete testing and revenue demonstration of any new system (Task 97-5); and

4 Facilitate implementation of software-based signal and operating systems by discussing potential revisions to the Rules, Standards and Instructions (49 CFR Part 236) to address processor-based technology and communication-based

operating architectures, including consideration of disarrangement of micro-processor-based interlockings, performance standards for PTC systems at various levels of functionality (safety-related capabilities), and procedures for introduction and validation of new systems (Task 97-6).

The results of the first two tasks are reflected in the body of this report. The third task--preparation of performance standards for processor-based signal and train control technology--is well underway. The report also describes the PTC Working Group's efforts to draft proposed regulations that will be technologically neutral and will facilitate the onset of PTC deployment by creating a higher degree of predictability regarding the manner in which regulatory approval will be achieved.

This report was not written to answer one of the most urgent questions regarding PTC–i.e., whether the FRA should mandate the institution of PTC functions on any significant portion of the Nation's rail lines. In January of 1998, the Board of Directors of the Association of American Railroads (AAR) accepted a challenge from Secretary of Transportation Rodney Slater and Administrator Molitoris to enter into a partnership for PTC systems development. The venue for this effort is a project initially funded by FRA under section 1010 of the Intermodal Transportation Efficiency Act of 1991 (now section 1103(3)(2) of the Transportation Equity Act for the 21st Century) on the designated high-speed passenger rail line between Chicago, Illinois, and St. Louis, Missouri. The project unites the State of Illinois, FRA, and the Class I railroads through the AAR (including the Union Pacific Railroad as owner of the line and Amtrak as the passenger train operator) in seeking development of a PTC system that can support high-speed passenger operations as well as conventional freight service with a high degree of safety and efficiency. The standards developed as a part of this project will be available for use with PTC developments on other rail lines. Funding is provided by the FRA, Illinois Department of Transportation and the AAR.

The first product of the Illinois Project, expected to be completed within this calendar year, will be industry standards for interoperability of PTC systems. Interoperability (which is more precisely described herein) refers to the ability of lead locomotives from one railroad to respond to the control of another railroad's PTC system while traversing that railroad's lines. Since shared power arrangements and various types of joint operations are becoming more widespread, rather than the exception in contemporary railroading, interoperability is important to realizing the safety and other benefits of PTC.

In addition to writing rules for the performance of PTC systems, the PTC Working Group will remain active over the next year (and perhaps beyond) to track the progress of the Illinois Project and other PTC efforts and to act as a broad-based advisory panel in support of these activities. The working group will report to the FRA Administrator regarding the progress toward PTC implementation and any actions needed to facilitate system deployment.

Making these investments attractive to freight and passenger railroads requires that PTC technology be shown to be reliable and capable of addressing customer needs in a more efficient manner than would be the case using alternative technology. The working group is hopeful that the Illinois Project and other technology development efforts underway on major railroads will provide the confidence needed to support, first, large-scale revenue demonstration of the technology and, second, broad deployment on the core of the national rail system.

Over the past year of deliberations, the PTC Working Group has come to appreciate that deployment of PTC involves significant technical challenges and will require a predictable and progressive public policy environment. PTC systems will not be deployed at an early date unless all responsible parties play a constructive role in advancing the technology and removing technical, economic and institutional barriers. The final section of the report addresses conclusions and recommendations that can provide the most favorable climate for development and deployment of PTC systems. Since development of policy within the Executive Branch of the United States Government requires coordination and clearance not feasible within the time available for preparation of this report, conclusions and recommendations related to Federal action should be viewed as the opinions of the non-Federal members of the RSAC. There will be materials published subsequently by the Department of Transportation, specifically identifying recommended Federal actions.

Safety is the primary focus of this effort. The National Transportation Safety Board (NTSB) has long advocated the implementation of systems that can provide positive train separation. The *"NTSB Most Wanted List of Transportation Safety Improvements"* includes the following recommendation: "Require a railroad collision avoidance system."

The 1994 Report to Congress concluded that the various attributes of PTC would improve railroad safety and enable improved management of train operations in a variety of ways and at lower cost than conventional train control systems. Subsequently, the FRA created a Positive Train Control (PTC) working group within the Railway Safety Advisory Committee (RSAC) that defined three core functions of PTC. These core functions would:

Prevent train to train collisions (positive train separation).
Enforce speed restrictions, including civil engineering restrictions and temporary slow orders.
Provide protection for roadway workers and their equipment operating under specific authorities

VIII. The Role of Current and Forecasted Railroad Traffic to National Transportation

The railroads play a critical and growing role in moving our nation's freight — 39 percent of the intercity traffic measured by weight and distance (ton-miles), compared to 29 percent for trucks.~~1~~[1] Since the early 1980's, the railroads have increased their traffic (tons) by 25 percent, while their network (miles of road owned) declined by 34 percent.~~2~~[2] This resulted in increased traffic density by concentrating traffic over a smaller network. In the last few years, the railroads have expanded capacity by double-tracking track, such as CSX has done in Ohio (or even triple or quad tracking, in some cases), and opening previously closed routes, such as the BNSF's repurchase and reopening of the Stampede Pass line in Washington state. Positive train control is a way of further increasing capacity to accommodate traffic growth with the existing track infrastructure.

Rail traffic measured in revenue ton-miles has grown by 35 percent during the ten year period 1988-97.~~3~~[3] In 1997, the railroads originated 25 million carloads of traffic. The following commodities account for 73 percent of the total carloads originated: intermodal (trailers and containers on flatcars) (7.2 million carloads), coal (6.7 million carloads), chemicals (1.7 million carloads), motor vehicles and equipment (1.4 million carloads), and grain (including soybeans) (1.2 million carloads). ~~4~~[4]. Commuter rail ridership has grown by 14.9% during the ten year period 1987 – 97 and by 37.9% in the last fifteen years. Intercity ridership has grown by x% (Amtrak).

The nation's commuter rail operators currently carry over 1.2 million passenger trips a day and in some cities, such as Chicago and New York, they are carrying a significant share of the commuters traveling to jobs in the central city. In Chicago the 1990 census reported that Metra carried 21% of the work trips to the downtown area and in the New York region commuter rail operators served 78.8% of the Manhattan-bound work trips from Fairfield County, CT, 67.9% of the trips from Long Island and 70% of the trips from Mercer County New Jersey were made on commuter rail**.**

Impact of Forecasted Rail Traffic to National Transportation

The nation's highways are already congested. The Federal Highway Administration reports in its "1997 Status of the Nation's Surface Transportation System: Condition and Performance, Report to Congress" that 52 percent of the urban interstate highways were congested in 1995.5[5] Rail intermodal traffic is the fastest growing segment of railroad traffic and is forecasted by Standard & Poor's DRI to increase by nearly 5 percent per year between 1997 and 2003, an increase of nearly 8,000 trailers and containers per day during the period.~~6~~[6] These intermodal units are carried long distances, the

average length of haul exceeding 1,400 miles.[7] In a worst case scenario, in which no more intermodal traffic could be moved in 2003 than in 1997, because of railroad capacity constraints, this traffic would be shifted to highway, increasing vehicle miles traveled (vmt) in 2003 by 4 billion. This traffic would be in addition to combination trucks' 68 billion vmt (up from 55 billion vmt in 1995 on urban and rural interstates[8] based on forecasts by Standard and Poor's DRI of motor carrier volume growth[9]). Congestion would increase because lane miles of interstate highway capacity are expected to increase only minimally during this time period.

Additional vehicle miles traveled on the interstate system due to lack of railroad capacity would also increase highway accidents. Based on National Highway Traffic Safety Administration accident frequency statistics, highway accidents involving large trucks would increase by 107 fatalities and 2,096 injuries.[10]

Importance of Current Railroad Traffic to National Transportation

Currently, the railroads carry roughly 170,000 trailers and containers per week or over 24,000 per day.[11] If the railroads, for capacity reasons, could not carry this intermodal traffic, a significant commitment would be required of the approximately 1.7 million heavy (class 8) trucks just to move this freight.

The railroads are significant intercity carriers of hazardous materials. The Bureau of Census and U.S. Department of Transportation "1993 Commodity Flow Survey" found that railroads hauled 45 percent of the combined highway and rail intercity ton-miles of hazardous shipments.[12] The Surface Transportation's Board's "Carload Waybill Sample" as summarized by FRA indicates that 94 million tons of hazardous materials were moved by rail in 1996, thereby keeping a substantial amount of this commodity off the highways. In particular, there were an estimated 889,000 tank car shipments traveling an average of over 700 miles per shipment. Three or four tank trucks would be needed to substitute for each of these rail shipments. Specialized tank trucks, however, are not commonly available.

Plastics manufacturing depends on chlorine, which is one of the most rail-dependent chemicals, because of safety requirements. More than 75 percent of all chlorine shipped in the country is handled by rail. The remainder moves by barge, which is very slow, and by small pressurized tank trucks, which are not available in adequate supply for moving large quantities of chlorine. Polypropylene and polyethylene, used in the production of plastic containers, move over 75 percent by rail covered hopper cars. These products are too voluminous (nearly 170,000 carloads in 1996) to move by truck[13]. In addition, transloading the product from railcar storage to truck raises the possibility of product contamination due to multiple handling. Another commodity, ethylene oxide, used in the manufacture of numerous products, from solvents to plastic wrap, moves nearly entirely by rail.

Phosphate rock, potash and other raw materials used to produce fertilizers are largely transported by rail, and over 35 percent of fertilizer and agricultural chemicals products are also moved by rail. Although some raw materials and finished goods move relatively short distances to local mixing plants that might be accommodated by truck, and while barges handle a considerable share of the Mississippi River traffic after the initial move from Florida mines or processing plants, the volumes shipped by rail are so large that substitution of another mode would be difficult and expensive. In addition, one key input in fertilizer production, nitric acid, is nearly 100 percent carried by rail into production plants.

The railroads are relied upon heavily to move the majority of the nation's coal shipments. Railroads handle 55 to 60 percent of total U.S. coal production, and large segments of the coal mining industry use the railroads to deliver coal to power plants, steel mills, and other industrial customers, or for delivery to river and ocean ports for movement by water to domestic and overseas destinations. Many Appalachian mines are not accessible by truck or other alternate transport service. The large volumes of coal could strain the capacity of the coal truck fleet as well as the road network and unloading facilities at the point of consumption. The even greater volumes and longer distances involved in many coal movements from western mines

would make substitution of truck service impractical.

The motor vehicles and parts industry relies heavily on rail service for both inbound parts and outbound assembled vehicles. The availability of customized rail service permits auto manufacturers to hold only a few days supply of parts inventory. In addition, the railroads play a major role in the transport of assembled autos to distribution points for local delivery to auto dealers. In 1996, the railroads moved more than one million rack cars shipments of assembled motor vehicles or more than 80 percent of this traffic. The railroads also moved over 400,000 carloads of motor vehicle parts. Each of these commodities moved nearly 1,000 miles on the average.[14]~~14~~

In the paper, pulp, and allied products industry, high proportions of pulp and paper mills' raw materials and finished goods move by rail. Shipments of key raw materials, such as wood pulp, clay, caustic soda, lime, and sulfuric acid rely heavily on rail and are too voluminous to move by truck. Other modes of transport are not price-competitive with rail for moving pulp from the southeastern U.S. to paper mills in Wisconsin and Michigan. In addition, the older mills do not have loading facilities suitable to receive pulp by truck. Rail is also used for moving pulpboard from paper mills to the converting plants where corrugated shipping containers and folding cartons are produced, because trucks are not a cost-effective substitute.

Glass manufacturers are extremely dependent on rail service, because they require soda ash, produced primarily in Wyoming and California at facilities that ship entirely by rail (or by short-distance truck to rail). Manufacturers cannot practically store substantial amounts of soda ash, because precautions are needed to prevent its contamination.

USDA reports that in 1995, rail moved 66.1 percent of wheat tonnage and 36.5 percent of corn tonnage. Overall, rail moved 40.0 percent or 152 million tons of all U.S. grains (and soybeans), or nearly the same amount of grain moved by truck in 1995 (155 million tons).[15]~~15~~ Although many grain movements can be handled by truck, or by truck in combination with barge, the truck fleet is not large enough to accommodate all rail-borne traffic. The beverage sector relies heavily on rail for the delivery of sugar, high fructose corn syrup and other important raw materials.

In the copper mining industry, rail carries roughly two-thirds of the shipments of concentrated copper ore to refiners and smelters. The production of iron ore pellets in the Upper Peninsula of Michigan relies on rail for receiving bentonite clay, an essential additive, from Wyoming. Much of the iron ore moves to Lake Michigan and Lake Superior by rail for water delivery to steel mills located on Lake Michigan and Lake Erie. A large quantity moves by rail to land-locked steel mills.

Truck Driver Shortage

The president of the ATA, Walter McCormick, Jr. recently stated that "the trucking industry has identified the lack of trained drivers as its top concern..."[16]~~16~~ If growth in rail intermodal traffic could not be accommodated by the railroads and moved to the highway, the shortage of truck drivers would worsen, because of the unattractiveness of long distance to truck drivers.

Commuter Operations

Commuter ~~Rail operations~~rail, using locomotives or electric or diesel powered self propelled equipment, has proven to be an efficient and effective way to get commuters to work destinations in traditional central cities and, increasingly, to suburban work locations. Commuter rail has been the fastest growing segment of the public transit industry and the rapid growth in ridership reflects the establishment of new systems, the expansion of ridership on the older passenger rail systems, and new expansion into the suburban passenger rail market. An example of this new market can be seen in Los Angeles where Metrolink recently opened the new Riverside line that provides service between Riverside and Orange Counties and does not go downtown. Today the Nation's

16 commuter rail systems operate over 4,200 scheduled trains each weekday.

Since 1996 commuter rail operations have started up in Dallas (Trinity Railway Express) Texas and Stockton (Altamont Commuter Express) California. New commuter rail operations currently under development and scheduled to open by the end of 1999 include a 20 mile commuter rail operation in Burlington, VT and a 40 mile operation in Seattle, Washington. In 2000, Trinity Railway Express is scheduled to open 14 additional miles of service to Ft. Worth, pushing ridership from the current 2000 riders a day to over 8,000.

Established commuter operations are also expanding to meet ridership demand and to combat urban congestion and air quality problems:

- In Boston, the New Colony Line was opened in 1997 adding a total of 26 train trips a day from Plymouth and Middleboro serving over 13,000 daily riders, significantly exceeding estimates. Currently over 8 additional commuter rail extensions are under consideration in Boston.
- In Los Angeles, Metrolink, which began operations in 1992 with 50 trains a day carrying 2,800 passengers a day, has expanded to 128 trains carrying almost 30,000 passengers a [17]day. Two additional extension projects are currently under study by the railroad.
- In Philadelphia, where SEPTA's commuter rail operations carry 90,000 riders a day, an investment and environmental study has been completed for a 48 mile suburb to suburb line extending from Morrisville on the east to Glenloch located west of the City.
- In New Jersey, the reactivation of commuter service is being studied on the New York and Susquehanna & Western line and on the West Shore line.
- The Long Island Railroad is currently developing the East Side Access project which will to permit its trains to reach Grand Central Terminal, as well as Penn Station, an effort that will improve travel time for 30% of the LIRR's over 75.8 million passengers a year. This project alone is projected to generate travel time savings valued at $69.6 million dollars a year and reduce carbon monoxide emissions by 720 tons a year, nitrogen oxide by 124 tons and volatile organic compounds by 76 tons.[18][19]
- In Chicago Metra currently has 15 system expansion projects under design or study and the Northern Indiana Commuter Transit District is studying the possible addition of its first new line since the system opened in 1908.

The American Public Transit Association's 1998 Fixed Guideway Report [20][21]identifies 123 new commuter rail projects, totaling 3,326.6 miles that are currently being proposed, planned, designed or constructed; more than doubling the 3,162.6 miles of commuter rail service currently in operation. The Transportation Efficiency Act for the Twenty-First Century (TEA 21) authorized funding for more than 40 regional/commuter rail projects among the over 200 new start mass transit projects that are currently underway. Areas where new commuter rail systems are under development include: Atlanta, Cleveland, Detroit, Denver, Kansas City, Madison, Minneapolis, Nashville, Providence, Raleigh, Salt Lake City and Tampa.

One of the central reasons that commuter rail is viewed as such an attractive solution to urban transportation problems is the potential opportunity to utilize freight railroad rights-of-way. It is much easier to obtain public support for these projects, and they can usually be completed at a much lower cost, when existing transportation corridors are used. Mass transit investments that expand freight railroad capacity or reactivate abandoned rail lines to permit the introduction of passenger rail service, are frequently viewed as the best investment of public transit funds.

Commuter rail services generate benefits for both the commuter and the non-commuter estimated at over $5.26 billion a year[22][23]. For every dollar invested in commuter rail there is an economic return of up to $6. These benefits include cost savings from reduced traffic accidents and fatalities, congestion mitigation cost savings for all commuters and reduced traffic delay costs for commuter rail riders, as well as other environmental mitigation and general cost savings. In addition, commuter rail operations across

the nation have served as an important catalyst for regional economic growth, job creation and enhanced property values. For example, homes around transit stations are valued from 2 to 10% higher than comparable properties not within walking distance.

The growth of commuter service over existing freight lines increases the competition for existing railroad capacity. This is a contentious issue; commuter operators are negotiating for longer hours of operation to attract additional rail commuters, while the freight railroads are trying to minimize the interruptions to their growing freight train service. Positive train control could provide increased capacity and safety allowing these two rail functions to use the same tracks, through more efficient dispatching and assured physical separation. Commuter operations were recently started in Dallas and other cities are planning new service. In Los Angeles and Washington, DC, growth in both freight and commuter service has led to capacity concerns. PTC could provide for major expansions in commuter rail, because neither the freight railroads nor the commuter operations in their negotiations are willing to make the investments to provide the additional capacity needed.

Intercity Rail Operations

Amtrak continues to progress a managed growth program primarily using freight-owned rail lines. Substantial freight growth combined with prioritized higher speed intercity rail passenger train operations often strains the available capacity on many of the most strategic freight corridors.

Amtrak, in concert with the Federal Railroad Administration and the State of Michigan, are continuing to progress the first proven communications-based High Speed Positive Train Control Project (HSPTC) in the Western Hemisphere. This new, advanced technology system will provide an enhanced level of safety to train operations, and protected grade crossings. Properly managed, HSPTC could enhance corridor capacity, fuel efficiency, and significantly reduced operating schedules.

Amtrak is continuing to progress increased average rail passenger train speeds jointly with increased freight train speeds. As both average speeds are increased, the capacity and fuel efficiency of the corridor is increased, without dramatic or costly infrastructure improvements. HSPTC will dramatically enhance the operation of high speed rail passenger service while simultaneously strengthening joint freight operations.

Fuel Consumption

In FRA's 1991 study, "Rail vs. Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors," it was found that rail achieved higher fuel efficiency, measured by ton-miles per gallon, than trucks in all 32 scenarios. The scenarios varied by train type, such as mixed freight, TOFC, double-stack, and by varying numbers of cars. The scenarios were analyzed by using a train performance simulator and the Cummins Engine Company vehicle (truck) mission simulation model. Rail achieved from 1.4 to 9 times more ton-miles per gallon than competing truckload service.

Positive train control c~~w~~ould generate additional fuel savings to the railroads by allowing them to improve operations and scheduling. This c~~w~~ould reduce fuel-consuming bottlenecks in rail corridors and delays in yards. PTC, by pinpointing train locations, c~~w~~ould permit railroads to adjust train speeds needed for going off of the main track to a siding to allow another train to pass or to make connections in yards, thereby avoiding traveling at higher than necessary speeds and unnecessary waiting. The BNSF estimated~~s~~ that it could save $24 to $40 million per year in fuel costs by moving at more constant speeds rather than the current pattern of hurrying up and waiting.[24]~~17~~

Environmental Impacts

FRA in its "Intercity Freight and Passenger Rail: State and Local Project Reference Guide," presented examples of the environmental benefits of intercity rail service. FRA cited FHWA's 1995 "Intermodal Freight Transportation," Volume 2

on the benefits of rail/truck intermodal transportation: "An efficient, coordinated long-distance truck-rail-truck intermodal movement can be up to 3.4 times more fuel efficient that a non-intermodal truck movement while emitting only 20 percent as many hydrocarbons."[25]

The Task Force of the Internal Combustion Engine Division of the Council on Engineering of the American Society of Mechanical Engineers, in its May 1992 "Statement on Surface Transportation of Intercity Freight" concluded that "there is potential for large savings in fuel consumed along with a similar reduction in engine exhaust emissions if the rail mode is used to a greater extent for movement of intercity freight." (p. 5) This conclusion was based on their analysis using data from published studies on fuel consumption and vehicle emissions for rail and truck.

FRA in its "Intercity Freight and Passenger Rail: State and Local Project Reference Guide," presented examples of the environmental benefits of intercity rail service. FRA cited FHWA's 1995 "Intermodal Freight Transportation," Volume 2 on the benefits of rail/truck intermodal transportation: "An efficient, coordinated long-distance truck-rail-truck intermodal movement can be up to 3.4 times more fuel efficient that a non-intermodal truck movement while emitting only 20 percent as many hydrocarbons."[26]

III. Train Control Systems and PTC ~~Architectures~~ ~~*(RSAC Progress Report Group, [points of contact are Chuck Dettmann, Grady Cothen, and James Stem until team make-up has been determined])*~~

A. Introduction~~Train control systems and allied technologies [explain similarities and differences between train control systems and other technologies than address one or more PTC functions]~~

~~***Commentary: Add introduction of how technology has enabled advancements in safety and efficiency of operations. Add some history; e.g., describe traditional signaling technology (Possibly extract portions of Bob Gallamore's article in Railway Age). Discuss proven safety record, fail safe concepts, closed loop, cab signals, and PTC concepts. – Need to be sure it doesn't duplicate information presented in Section I. Some of this material is in the 1994 report.***~~

~~***Should compare different systems based the system functional elements (location system, communications, operator display, how/where safety problem is identified, how system reacts to detected problem). Should discuss how different systems address different risk areas and achieve different levels of risk reduction.***~~

~~***Possible areas in which systems may differ: approach to monitoring and detection, processing, prevention, actions taken.***~~

As with all transportation systems, railroad operation requires the management of time and space. By controlling time, space can be allocated for operations. With low density operations time is less critical, but with high speed, dense operations time becomes more critical. The evolution of railroad control systems followed this principle. In other words, greater knowledge of location and faster communication of that knowledge is key to improving railroad capacity, efficiency and safety. The railroad is a single degree of freedom system. The train can go either forward or in reverse, but cannot pass, except where there are sidings. Trains travelling at greater than restricted speed (15-20 mph or so) cannot stop within sight distance, and systems that provided for safe operation that did not rely on the operator seeing an opposing train were developed. The railroads developed rule based systems to allow for greater speeds and to manage the allocation of space.

There are three major methods of train operations on main tracks in the U.S; signal indications; voice train movement authorities; and manual block rules. PTC systems under development are centered on one or more of these methods of operation.

Operations by Signal Indications

Operations by signal indications occur at interlockings, in traffic control systems or automatic block signal systems on two main tracks arranged for movement with the current of traffic. Trains having authority to enter these systems are governed by the indications of signal aspects that are arranged to provide for movement at maximum authorized speeds; provide sufficient distance to slow a movement in approach to the point where speed is to be reduced; and provide sufficient distance to stop a movement at the point where a stop is required. Absent control devices that supplement the signal systems to enforce maximum authorized speed and speed reductions (e.g., automatic train control or automatic trainstop), compliance is dependent upon the locomotive engineer to properly control the speed of a train. With or without supplementary control devices, it is dependent upon the locomotive engineer to stop a train at a point where a stop is required.

Operations by Mandatory Directives

Operations by train orders may occur in either automatic block signal territory or non signaled territory. Train orders are mandatory directives that affect the movement of trains and are identified on various railroads as track warrants, track permits, track bulletins, block authorities and Form D. Train orders provide the authority for the movement of a train and may be used for the protection of roadway workers and on track equipment.

Train orders are orally issued by the dispatcher to a train crew member who must repeat the orders back to the dispatcher for verification of correctness. Train orders authorize the movement of a train between specific points and provide instructions for meeting or passing other trains, speed restrictions and other special conditions. Where automatic block signals supplement operations by train orders, indications of signal aspects furnish train crew members information about block conditions in advance and provide sufficient spacing to slow or stop a train as may be required. The dispatcher is relied upon to issue train orders that provide for the safe movement of trains. It is dependent upon train crew members to comply with both the instructions contained in train orders and the indications of a block signal system.

Operations by Manual Block Rules

Manual block rules are used for the movement of trains on designated portions of several railroads. In a manual block system the railroad is segmented into blocks of designated lengths. Train orders are issued by a block operator or dispatcher and provide authority for a train to enter a block or blocks. No train may be permitted to enter a block occupied by a passenger train or an opposing train; a passenger train may not enter a block occupied by another train; but a freight train may follow a freight train into a block provided the following train proceeds prepared to stop in one-half the range of vision but not exceeding 20 mph. Block operators are relied upon to assure each block is unoccupied before permitting a train to enter the block. It is dependent upon train crew members not to enter a block without authority, to properly control the speed of the train and stop where a stop is required.

Other Methods of Operation

For branch lines, industry tracks, other auxiliary tracks and yards, various methods of operations are employed for the movement of trains. Voice rules and yard rules are used in yard operations and switching services on industry tracks. Yard limit rules are used on main tracks extending through yards and stations and on branch lines. Timetable special instructions are utilized on branch lines, industry tracks and in conjunction with train orders on main tracks. All of these methods of operations rely upon dispatchers, operators, yardmasters and train crew members to be learned in the rules governing the methods of operations, issue succinct orders orally, and comply with all the

requirements. Certain PTC projects have addressed train operations on auxiliary tracks, branch lines and yards in order to restrict unauthorized entry onto the main track.

Requirements for Signal and Train Control Systems

Federal regulations exist that prohibit the operation of a freight train at a speed of 50 or more miles per hour or a passenger train at a speed of 60 or more miles per hour unless a manual block system or a block signal system is installed and prohibits the operation of any train at 80 or more miles per hour unless an automatic cab signal, trainstop or train control system is installed.

An automatic block signal system or a traffic control system is required to support the installation of automatic cab signal, trainstop or train control systems. Cab signal, trainstop and train control devices are installed on board locomotives and, accordingly, supplement the block signal or traffic control system. Track circuits or devices along the wayside are used to communicate signal system status to the on board equipment.

Automatic cab signals are inductively connected to track circuits and convey aspects on board that indicate the condition of the block being traversed and the blocks in advance. No enforcement is provided by automatic cab signals and train crew members are relied upon to comply with the indications displayed, properly controlling the speed of the train and stopping where a stop is required.

Automatic train control devices augment automatic cabs signals and provide enforcement of speeds associated with signal indications. When a more restrictive cab signal indication is obtained, the locomotive engineer must immediately take action to reduce the train speed to that prescribed by the signal indication or the train control device will initiate a brake application to stop the train. The most restrictive cab signal indication permits a speed not exceeding 20 mph. It is dependent upon the locomotive engineer, at speeds of 20 mph or less, to stop the train were a stop is required.

Automatic trainstop devices also augment automatic cab signals but do not provide enforcement of speeds. When a restrictive cab signal is obtained, the locomotive engineer must acknowledge the restrictive cab signal within a prescribed period of time or the trainstop device will initiate a brake application to stop the train. The locomotive engineer is relied upon to properly control the speed of the train after acknowledging a restrictive cab signal and to stop the train where a stop is required.

An automatic trainstop device may be utilized without cab signals by being intermittently inductively connected to the wayside signal system (i.e., at each signal location). When a train passes a wayside signal displaying a restricting aspect, the locomotive engineer must acknowledge the restrictive indication within a prescribed period of time or the trainstop device will initiate a brake application to stop the train. It is dependent upon the locomotive engineer to control the speed of a train after acknowledging a restricting wayside signal indication and to stop the train were a stop is required.

B. Current PTC system concepts ~~(see Rich McCord comments)~~

Although the safety record of the railroads is exemplary, train collisions, overspeed derailments and accidents with maintenance of way workers, have generated a demand from the regulators, labor and management to develop cost-effective systems that could significantly reduce the risk of these types of accidents. As a part of the RSAC process, an accident review team was established to analyze the accident record and determine which accidents might be preventable by PTC. In order to accomplish this task, the accident review team develop four design concepts to reflect the broad range of capability that can

address the PTC safety objectives, depending on operating territory and amount of risk reduction justified. The design concepts include augmentation of conventional cab signal systems, as well as the newer systems that use digital RF communications links.

The design concepts were developed based loosely on the functionalities of four current PTC projects (i.e. the Union Pacific Railroad (UPRR)/Burlington Northern Santa Fe (BNSF) Positive Train Separation (PTS) Pilot Project, the Amtrak/ Michigan DOT Michigan Line Incremental Train Control System (ITCS) Project, and the BNSF Train Guard™ System Project), and the design specifications originally proposed for the UPRR/Illinois Department of Transportation (IDOT) St. Louis Line Project that were based on the Advanced Train Control Systems (ATCS) Specifications.

The four design concepts are hierarchical, in that each superior design incorporates all of the functions of the previous concept(s), and may either add functionality or scope (coverage) or both. The design concepts, from the least functionality/ scope, to the most, are as follows.

PTC Level 1

This is the first level PTC design concept to meet the "core functions" as identified by the PTC RSAC:

Prevent train to train collisions (i.e. positive train separation)
Enforce speed restrictions, including civil engineering and temporary restrictions imposed by slow orders.
Protection from train movements for roadway workers and their equipment operating under specific authorities.

This level of PTC is based on providing specific location information on nearby trains and maintenance of way crews to the lead locomotive of a train. Onboard enforcement is based on either the failure of the engine crew to acknowledge a warning of a nearby train, or maintenance of way crew, failure to enter a signal aspect and obeying that aspect, or exceeding permanent or temporary speed restrictions.

Most of these systems will use a radio frequency (RF) link to provide information to the lead locomotive of a train.

PTC Level 2

The next level PTC design will depend on the issuance of specific movement authorities and the reporting of train and maintenance of way crew locations to the authority issuer. In addition, to the functionalities of PTC level 1, level 2 will provide:

A computer aided dispatch (CAD) system designed to prevent the issuance of overlapping authorities, and provide for the issuance and enforcement of speed limits and restrictions.
A digital communications link between the CAD system and the locomotives.

PTC Level 3

This design concept in addition to providing the functionalities of PTC levels 1 and 2, will provide:

Devices (Wayside Interface Units (WIUs)) that monitor each mainline wayside switch, signal, and protective device currently installed in traffic controlled territory, to reduce risk of operating over unsafe track. If new switches are required during implementation of a level 3 system, these switches will be tied into a wayside local area network (WLAN).

WIUs in non-signaled territory that monitor switch and protective devices.

PTC Level 4

This is the highest level PTC design concept, and is largely based on the level 40 Advanced Train Control Systems (ATCS) specifications. In addition to providing the functionalities of PTC levels 1, 2 and 3, level 4 will provide:

WIUs that monitor each mainline signal, switch and protective device. This may require the installation of devices on currently installed switches and protective devices.
Additional protective devices, e.g. slide fences, anemometers, high water, dragging equipment, hot box detectors, etc.
Additional track circuits, track continuity circuits or other risk reduction approaches for broken rail detection.
Track forces terminals (e.g. laptops or other technology with data link) for roadway machinery to reduce the risk of accidents involving track forces outside their authority limits.

Open-Loop vs. Closed-Loop Control

There are two general types of control systems: open-loop and closed-loop. An open-loop system is one in which there is no direct or automatic function to cause an action to occur as a result of the control process. In a closed-loop system, the control function does directly create an action or output. A PTC system is not simply open-loop or closed loop as one system. There are a number of control loops within a PTC system, and each of these may independently be open or closed. For example, a PTC system typically includes a dispatch subsystem, a data communications subsystem, a wayside system, and an on-board system. The onboard system includes the function of initiating a brake application.

In the case of PTC, the distinction between open and closed-loop is important as it relates to brake enforcement. In a closed-loop system, the PTC system will initiate a brake application if the conditions occur that require the train to stop. In an open-loop system, the train operator will get an alarm that a brake enforcement is called for, but it is up to the operator to initiate the brake application. Most PTC system configurations being developed or tested are closed-loop in the initiation of a brake application. Most existing types of train control are open-loop relative to brake application; the signal system or a verbal or written instruction may indicate that the train should stop before a certain point, but the brakes are only applied if the train operator takes the appropriate action.

The major safety benefits of PTC, particularly implementation of the core PTC functions, are related to the fact that the brake initiation function is closed-loop.

C: ~~Introduction that~~ compares ~~and contrasts~~ PTC with other methods of operation.

The railroad industry, with advocacy from the Federal sector, has pursued the development and implementation of communications-based train control systems for more than 15 years. The initial objective was to develop a train control system at less cost than conventional train control systems that provided equivalent or greater safety of train operations and business benefits. At least 12 projects have been undertaken during this time to develop communications-based train control systems, now colloquially termed Positive Train Control (PTC) systems. Three projects were unsuccessful, two of which were abandoned and one currently in suspension, because of prohibitive costs. Nine of the projects are presently in various stages of development.

The developing PTC systems appear to fall into three categories: those that will become stand alone systems; those that will be integrated systems; and those that will be overlay systems.

A PTC system of the stand alone type will not only augment the existing train control system but will absorb its functionality to the extent wayside signals may safely be removed. Safety computers at a central office, on the wayside and on board each locomotive will enforce the proper spacing of trains, all speeds and stop where a stop is required. Stand alone PTC systems will become the method of train operations.

PTC systems of the integrated type will be so interconnected with the existing train control system that its functionalities will be extended to equipment on board each locomotive that will enforce all speed and stop requirements prescribed by both the PTC and signal systems..

PTC systems of the overlay type will provide for among other things, enforcement of all speed and stop requirements while utilizing the existing train control system as the primary method of train operations.

Benefits of Adding PTC to Existing Methods of Operation and Signal and Train Control Systems.

The initial goal of replacing conventional signal and train control systems has been has been expanded to include PTC systems that augment the existing systems that still have many years of useful life. The current initiatives are to maintain the safety features and business benefits of existing systems while adding functions that cannot otherwise be obtained, e.g., enforcement of all speeds and absolute stop where a stop is required. Such functions will reduce human factors that contribute to collisions and derailments and some of the PTC systems will provide for more efficient movement of trains.

It is evident that each current method of train operation and operation in each type or combination of signal and train control system is heavily reliant on human performance to properly issue train orders, control train speeds and stop where a stop is required. PTC systems have the capability of constantly determining the location of a train in relation to current speed requirements, speed restrictions in advance, and the point were a stop is required. The systems are capable of enforcing all speed limits and stopping commands. Results of actual field tests of several PTC projects indicate that the systems have the potential to intervene before incorrect train orders or excessive speed imperil a train movement or a train passes a point where a stop is required.

[Add benefits to MOW employees](need write up from Stotts)

Positive Train Control Projects

Background

In late 1983, the Canadian National, British Columbia, Canadian Pacific, Burlington Northern, Norfolk Southern, Seaboard System, Union Pacific and Southern Pacific railroads jointly agreed to support an endeavor to identify operating requirements for a communications-based train control system. In 1984, under the auspices of the Association of American Railroads (AAR) and the Railway Association of Canada (RAC), the Advanced Train Control System (ATCS) project office was established. A technical consulting firm, ARINC, was retained to perform a technology assessment and design the system architecture with oversight provided by railroad officials.

The development of the specifications for ATCS took more than three years to complete in an open forum process with railroads, vendors and FRA participating in component drafting committees. The specifications are detailed enough to ensure component interoperability and system safety without limiting vendor ingenuity. The ATCS Specifications, are currently managed by the AAR.

Previous PTC Projects

Overview of the Advanced Train Control System (ATCS)

ATCS was built using off-the-shelf equipment and computers and was considered to be comprised of five major systems: the Central Dispatch System, On-Board Locomotive System, On-Board Work Vehicle System, Field System, and Data Communications System. Each of the systems fully complied with the ATCS Specifications in an open architecture.

The Central Dispatch System consisted of two subsystems - a console from which the dispatcher managed train operations that was linked to the ATCS system, and the Central Dispatch Computer. The console provided both an information display and data entry capabilities for the dispatcher. The Central Dispatch Computer was actually two interlinked computers, one that processed information to and from the dispatcher and other ATCS components, and the other that managed train movements with the objective of guaranteeing safe operations and minimizing train delays.

The Locomotive System also consisted of two subsystems - the locomotive display and the on-board computer (OBC). The display provided the interface between the engineer and the OBC; it displayed information about location, route, speed, speed restrictions, maintenance-of-way work locations, messages concerning the train movement, controlled point status and dispatcher advisories. The display contained a terminal from which the engineer could send and confirm information digitally with the dispatcher, field offices and other vehicles. The OBC performed on-board data processing and safety checking and handled data transmitted to and from the dispatcher, other locomotives, maintenance-of-way employees, and coordinated location tracking, enforcement, movement authorities switch monitoring and control, and health reporting. Transponders were placed along the railroad at strategic points (e.g., controlled points, approach to controlled points, interlockings, etc.) for location determination. An interrogater on-board the equipped trains read each transponder providing precise location, and track identification. At selected transponders, the OBC calibrated tachometers that were used to provide location in the intervening distances between transponders. The OBC was equipped a track database which contained information on the transponder locations, distances between transponders, and track configuration.

The Work Vehicle System consisted of two subsystems - a display that provided the interface between a maintenance-of-way foreman and ATCS which permitted the foreman to communicate digitally with the dispatcher or other vehicles and to be aware of nearby track activity and a Track Forces Terminal that performed data processing and safety checking to manage the movement of equipped work vehicles through the ATCS system.

The Field System consisted of wayside interface units (WIU) that provided remote control and monitoring of field devices. The WIUs performed internal data processing and error-checking, commanded the movement of controllable devices (e.g., moveable bridges or power-operated switches), monitored non-controllable and highway rail grade crossing devices.

The Data Communications System was a digital data radio network operating in the UHF radio spectrum. The communications hardware consisted of front end processors (FEP), cluster controllers (CC), base communications packages (BCP) and mobile communications packages (MCP). The FEP is the major entry point from the Central Dispatch Computer into the ATCS ground network and performs train location functions and protocol conversions. Each FEP is connected to serveral CCs. The CC is a routing node in the ground network, manages a base station and performs functions similar to the FEP but over a smaller geographical area (e.g., routing of messages to and from trains or wayside devices under its control). The BCP provides the interface to the ATCS radio frequency and may contain one or more base station radios (each on different channel pairs). Base stations may be connected to the Central Dispatch Office by land lines, leased lines, microwave, fiber optics or radio. The MCP is configured to perform an interface between the RF network and the locomotive computer and display; an interface between a RF network and a WIU; and/or an interface between the ground network and a wayside

equipment controller (e.g., code line messages). A MCP is required at each wayside equipment location and on each lead locomotive and selected maintenance-of-way vehicles to transmit and receive messages. The ATCS data transmitted over the network included message protocols that required a handshake (closed loop) in order to become effective or be implemented.

Overview of Canadian National ATCS Projects

Canadian National had three ATCS test or pilot projects between 1987 and 1995. The first, undertaken jointly with the AAR, between 1987 and 1989, was the development of a pilot locomotive display. The project used Canadian National's locomotive trainers and a human factors expert, and the display was tested extensively on CN's locomotive training simulator. Between 1989 and 1992, Canadian National developed an ATCS Test Bed near Toronto, Ontario to demonstrate the concepts of ATCS. This Test Bed, designed to operate transparently to the revenue operation, consisted of an office system linked to the dispatch system, locomotive systems and Wayside Interface Unit emulators. The system demonstrated the feasibility of train tracking, and the verification and issuance of movement authorities from the office system. The time to deliver and display authorities was less than three seconds. In addition, the tests demonstrated the feasibility of co-existence of train control messages and administrative messages.

Between 1989 and 1995, Canadian National developed a transponder-based system using the AAR ATCS specifications as a foundation for system architecture, functionality, and communications. The system was designed for use in dark territory as a lower cost alternative than CTC, and used Canadian National's Computer-Aided Manual Block System (CAMBS) as a front end dispatch system. It was connected to an ATCS Interface Computer (IC) which converted OCS clearances into ATCS Movement Authorities. The authorities were displayed on the ATCS IC graphical monitor for verification prior to being transmitted to the locomotive.
The territory was 188 miles long and had 13 sidings equipped with power switches monitored and controlled by Wayside Interface Units. The primary method of switch control was through the locomotive, either automatically when the train was operating with a Proceed Authority, and through locomotive engineer action when operating with a Work Authority. Switch position was displayed in the locomotive cab. Switches could also be controlled from the dispatch office for unequipped locomotives and engineering work equipment. The time from initiating the command to control a switch to confirmation on the locomotive display was approximately 15 seconds.

The system supported enforcement of permanent, temporary and turnout speed restrictions. It also supported the protection of track force work limits, into which a train could enter only after a password, provided by the track foreman by voice radio, was entered into the on-board system by the train crew and verified by the on-board system. The system included reactive enforcement of authority limits, and a form of predictive enforcement to prevent trains from traversing a switch that was not properly set.

In addition to the pilot territory, Canadian National equipped 40 miles in southern Ontario as a test bed. The project was a technical success, but was terminated when the industry appeared to be moving away from the ATCS program, as CN did not wish to be the only one adopting the ATCS technology.

The system was developed by Alcatel Canada, as system supplier and integrator, Vapor Canada and Motorola Canada.

Canadian Pacific Railway ATCS Pilot – Calgary to Edmonton

Canadian Pacific Railway (CPR) operated a revenue-service ATCS pilot on 190 miles of mainline track between Calgary and Edmonton, Alberta, Canada between 1993 and 1995. The objective of the revenue-service pilot was to develop an ATCS system in incremental steps with the constraints that each step must include: 1) a fall-back path to the previous step,

2) a progression path to the next step, and 3) thorough testing before revenue service implementation.

Technology pilots at CPR in the 1980's and 900 MHz radio testing in the late 1980's and early 1990's preceded the operational pilot and proved the technical viability of the major subsystems. Fourteen locomotives were then equipped for ATCS operation, with an additional four being partially equipped as spare locomotives should any of the 14 be removed from service. In-track transponders were then installed between Calgary and Edmonton and 900 MHz ATCS radios were added to existing radio towers to provide continuous radio coverage. During this time, the office dispatching software was upgraded to include a digital communication path to and from locomotives. This path would allow for the transmission and acknowledgement of clearances to, and the reception of track releases from, locomotives. This was in addition to the existing human interface used for voice dispatching.

The pilot project proved the operational advantages of the electronic delivery of clearances and track releases but also the high cost of maintaining the prototype equipment used. The costs of maintaining such a system were found to be prohibitive, both for retrofitting existing locomotives and for using a transponder-based location tracking system. Reactive and predictive on-board enforcement of authority limits were shown to be effective, although predictive enforcement required more extensive testing before it could be considered for revenue service use. The pilot was shut down in 1995 due to the rising costs of maintaining a prototype system in revenue service. The pilot successfully demonstrated that an incremental approach allows for a manageable migration from existing operations.

~~It is anticipated that an industry focus on high reliability on-board electronics in new locomotive designs will reduce the life cycle costs of on-board equipment. GPS-based alternatives to transponders such as continent-wide DGPS and DGPS with Inertial augmentation, however, must be enhanced to support precision vital location tracking before they can be accepted as a safety-critical solution for railway use~~.

As a postscript, the ATCS frequencies have proven to be a good choice for codeline replacement. CPR is building out a 900 MHz trackside radio network for radio codeline and we envision using any spare capacity to support other trackside data applications. This network will be ready to support ATCS communications in our major corridors when the time comes.

Overview of the Advanced Railroad Electronics System (ARES)

ARES was conceived in 1984 and was similar to ATCS. Following considerable study, the Burlington Northern retained Rockwell International in 1986 to develop and test ARES in a real railroad environment. ARES utilized Rockwell built equipment and was considered to be comprised of three major segments: the Control Segment, the Data Segment and the Vehicle Segment. Each of the segments were built to proprietary specifications developed by the Burlington Northern and Rockwell.

The Control Segment consisted of a console from which dispatchers could monitor the positions and velocities of all equipped vehicles in traffic control territory, automatic block signal territory and non-signaled territory. The Control Segment produced traffic plans, displayed activity at three levels and information about consists, crews, and work orders for each train. In addition, the Control Segment monitored activity to ensure vehicles followed proper operating procedures and warned the dispatcher of violations of limits of speed and authority. Further, the Control Segment performed conflict checking of track warrants and other movement authorities before they were transmitted to trains and maintenance-of-way employees.

The Data Segment consisted of a communications network that provided data paths in the VHF radio spectrum between the mobile equipment, wayside equipment and the control center. It consisted of equipment similar to that of ATCS:

FEPs, CC, BCPs and MCPs. Digital data messages were routed by the FEPs and CCs to BCPs at base stations. The base station BCPs provided an interface to mobile vehicles for movement authorities, restrictions, and work orders and to wayside equipment to monitor and communicate the status of hand-operated switches, power-operated switches and signals through the network to the dispatcher.

The Vehicle Segment included both locomotives and maintenance-of-way vehicles. Locomotives were equipped with a receiver for Navstar Global Positioning Satellite (GPS) signals, to calculate train position and speed, a display that informed the crew members about movement authorities, the route ahead, work along the route, and the health of locomotives in the consist. The Vehicle Segment was equipped to apply a full service brake application if the crew was disabled, the train violated its movement authority or speed requirements. The maintenance-of-way vehicles were equipped with a GPS receiver to calculate speed and location, a device to digitally communicate with the dispatcher, and a printer to receive warrants, bulletins and work time in the field. The Vehicle System was equipped with a track database and periodically reported position and speed to the Control Segment. The ARES message protocols also included requirement of a handshake ~~(closed loop)~~ in order to become effective or be implemented.

ARES was implemented on a test bed of 230 miles of track in the Mesabi Iron Range in late 1986. The prototype equipment was installed on 17 locomotive and 3 maintenance-of-way vehicles. The test bed was utilized for more than four years to successfully develop, test and prove ARES technology.

Overview of the Positive Train Separation (PTS)

In 1994, the Union Pacific and Burlington Northern (now Burlington Northern Santa Fe) jointly embarked upon development of a Positive Train Separation (PTS) system. GE Harris Railway Electronics was retained to develop and test PTS. PTS had three major segments: the Locomotive Segment; the Communications Segment; and the Server Segment. PTS utilized the communications network that exists on each railroad with only minimal changes. BNSF used a VHF network and UP used a UHF network. The Locomotive Segment and Server Segment were built to UP/BNSF and GE Harris specifications in an open architecture.

The Locomotive Segment consisted of an on-board computer (OBC) with a cab display. Each locomotive was equipped with a GPS receiver, a differential GPS (dGPS) receiver and a mobile communications package (MCP), connected to the OBC. The OBC contained a track database and performed data processing to monitor location, calculate braking curves, calculate speed, receive authority limits, and apply the brakes if the authority or speed limits were projected to be exceeded. The OBC transmitted position data and violation messages to the server. Buttons on the bezel of the display provided means by which the locomotive engineer could digitally communicate with the dispatcher.

The Server computer was interfaced to a console from which a dispatcher could monitor and direct train movements and to the communications segment for transmitting and receiving data to and from trains. The Server generated movement authorities on the basis of those issued by the dispatcher, established and transmitted authority and speed limits to trains, and received position data and violation messages from trains.

The communications segment on the UP provides data paths in the UHF radio spectrum between the mobile equipment, wayside equipment and the control center. The communications segment on the BNSF provides data paths in the VHF radio spectrum between the mobile equipment, wayside equipment and the control center. Both communications networks consists of equipment similar to that described for ATCS: FEPs, CC, BCPs and MCPs. The message protocols of both systems contained the requirement for acknowledgement (closed loop) in order to become effective or be implemented.

PTS was installed in a testbed extending from Blaine, Washington, to Pasco, Washington, on the BNSF, and between

Vancouver, Washington, and Hinkle, Oregon, on the UP, a total distance of about 865 track miles. The segment between Tacoma, Washington, and Vancouver, Washington, is joint trackage on which base stations operating in the UHF radio spectrum was installed in order to achieve PTS interoperability between trains of the two railroads. PTS protype equipment was installed on 20 locomotives, 10 from each carrier. The test bed was utilized for more than four years to successfully develop, test and prove PTS technology. The PTS project is complete.

Current PTC Projects

Overview of the Incremental Train Control System (ITCS)

In 1995, the Michigan Department of Transportation, in cooperation with Amtrak and Harmon Industries, was granted funding by the FRA for a demonstration of a high-speed positive train control system on an Amtrak line extending between Porter, Indiana, and Kalamazoo, Michigan. ITCS consists of three major segments - the Wayside Equipment Segment, the Communications Segment and the Locomotive Segment. Each of the segments ~~were~~ was built to proprietary specifications developed by Amtrak and Harmon Industries.

The Wayside Equipment Segment is comprised of wayside interface units (WIU) at each control point, intermediate signal, electrically-locked hand-operated switch and highway rail grade crossing signal. The WIUs monitor switch position, track circuit occupancy and signal aspects displayed in the traffic control system and the health of highway rail grade crossing.

The Communications Segment consists of two parts - a spread spectrum wide local area network (WLAN) that connects the WIUs to wayside interface unit-servers (WIU-S) that in turn broadcast digital data messages to trains in the UHF radio spectrum. There are 8 WIU-Ss spaced about 10 miles apart along the railroad. WIUs are slaves to WIU-Ss and continuously report via the WLAN the status of the device(s) being monitored to their assigned WIU-S. The WIU-S broadcasts (open loop) the status reported by the WIUs once every six seconds. Each WIU-S is provided with a track database for the territory it serves including maximum authorized speed and speed restrictions. An office to wayside land line provides means for the control operator to issue or void temporary speed restrictions to the track databases of the WIU-Ss.

The Locomotive Segment consists of an on-board computer (OBC) and cab display. The cab display provides the interface between ITCS and the locomotive engineer by continuously displaying the maximum authorized speed, actual speed, distance to targets, type of targets and target speeds. The OBC stores a database of signal indications, track curvature, gradients, mileposts, civil speed limits, speed restrictions and the locations of all devices with which it may be required to communicate. The OBC continuously calculates braking distances to targets, monitors current speed, upcoming speeds and initiates a full service brake application if the maximum authorized speed is violated or the train is not properly slowed for an upcoming speed restriction or requirement to stop. The OBC establishes a session with each WIU-S when it enters its zone of coverage, verifies that it has an updated track database and expects to receive a WIU-S broadcast every six seconds. The OBC can miss two broadcasts without adverse affects but a missed third broadcast (18 to 20 seconds elapsed time) results in the OBC initiating an automatic brake application, stopping the train.

ITCS is designed to prestart highway rail grade crossing signals at train speeds above 80 mph. The grade crossing signals have conventional approach track circuits designed to provide 30 seconds warning for train speeds of 80 mph. The approach to an active grade crossing system is determined by the OBC from the track database. At speeds above 80 mph, a session is then established via the WIU-S with the crossing WIU and the OBC provides an estimated time of arrival. If the crossing WIU indicates it is armed and functioning as intended, the train may proceed at speed and the crossing will provide the required 30 seconds warning. The estimated time of arrival at the crossing is updated every 5 seconds until the train reaches a point 30 seconds from the crossing. If a crossing does not arm or indicates it is not functioning as intended, the OBC will initiate a full service brake application to slow the train before it reaches the crossing. ITCS will restrict the

movement of subsequent trains at a failed crossing to 15 mph until the crossing device is repaired.

ITCS was installed in a testbed on Amtrak's Michigan Line between milepost 175 and milepost 195. Since 1995, the testbed has been utilized to develop, test and prove ITCS technology. ITCS is scheduled to be implemented in revenue service in mid 1999 between milepost 145, near Kalamazoo, Michigan, and milepost 216, near New Buffalo, Michigan.

Overview of the Advanced Civil Speed Enforcement System (ACSES)

Amtrak has received FRA approval to install ACSES in the Northeast Corridor (Final order of particular applicability, FR39343, July 22, 1998). ACSES will augment the 4-aspect cab signal system to nine aspects and will utilize transponders of a European design to achieve maximum authorized speeds up to 150 mph, enforcement of civil speeds, temporary speed restrictions and absolute stop. Amtrak has retained Parsons Brinckerhoff to develop, test and implement ACSES using off-the-shelf equipment in an open architecture.

The existing cab signal and train control system utilizes a 100 Hz coded carrier transmitted in the rails to provide for speeds of 20 mph (Restricted Speed), 30 mph, 45 mph and maximum authorized speeds up to 125 mph at code rates of 0, 75, 120 and 180 pulses per minute, respectively. The 9-aspect system will be achieved by the addition of a new 250 Hz coded carrier that, in combination with the 100 Hz coded carrier will provide aspects for enforceable speeds of 80 mph, 125 mph and 150 mph. The addition of a new code rate, 270 pulses per minute, will provide aspects for enforceable speeds of 60 mph and 100 mph.

Transponders will be placed in the approach to speed-restricted zones. The transponders will provide data to on-board equipment that includes distance to the beginning of a speed restriction, type of speed restriction, target speed, average grade to the restriction, distance to the next transponder and message verification information. The on-board computer, through data from a tachometer, will monitor the train's performance and, if necessary, initiate an automatic brake application to prevent entering the speed restriction at a speed above that prescribed.

Transponders will also be placed in the approach to interlockings to provide for enforcement of absolute stop when the interlocking signal displays an aspect requiring stop.

ACSES will permit the continued operation of all the users of the Northeast Corridor at existing speeds. A similar system, compatible with ACSES, is planned for installation on the New Jersy Transit which connects with Amtrak in New Jersey, and operates over that part of the Corridor extending between Philadelphia, Pennsylvania and New York, New York.

The intial installation of ACSES is underway between New Haven, Connecticut, and Boston, Massachusetts.

Overview of the New Jersey Transit Project (NJT)

A project similar to and compatible with Amtrak's ACSES system is planned for installation on 132 route miles of the New Jersey Transit (NJT). NJT also connects with Amtrak in New Jersey and operates more than 300 trains daily over that part of the Northeast Corridor extending between New York, New York and Philadelphia, Pennsylvania and over the Atlantic City Line extending between Philadelphia, Pennsylvania and Atlantic City, New Jersey.

Like ACSES, the NJT system will be transponder-based to provide for enforcement of civil speeds, temporary speed restrictions and absolute stop where stop is required. Installation of a nine aspect cab signal system on board NJT locomotives will provide the interoperability necessary to operate at higher speeds and closer headways in the Northeast Corridor.

Overview of the CR/CSX/NS Positive Train Control Platform Project

In 1997, Conrail, CSX Transportation and Norfolk Southern railroads received a grant from the FRA to develop, test and demonstrate an on-board PTC platform.

A determination was made that the design specifications would be object oriented with a standard locomotive bus. The objective is to develop an on-board platform which will accommodate inputs from any type of system governing the method of train operation (e.g., block signal systems, ATCS, ARES, PTS, ITCS, etc.) in order to facilitate interoperability.

The project was scheduled in two phases. In Phase I, the plans are to complete the design specifications~~, issue a request for proposal RFP to define the system hardware, issue a RFP for a~~develop two prototypes, contract for prototype hardware and complete the testing of prototypes. In Phase II, the plans are to issue a RFP for PTC design, contract for PTC design and prototypes, and conduct demonstration testing in the test bed between Manassas, Virginia and Harrisburg, Pennsylvania. ~~The railroads have retained~~ Wabco ~~to develop~~completed the design specifications in an open architecture, and the standard messages. ~~Wabco and GE-Harris have been retained to develop the interoperable on-board prototypes to be tested in 1999.~~ Wabco and GE-Harris were selected to build prototypes to prove the specification and Safetran was selected to provide two individual "objects" to be tested for interoperability with the Wabco and GE Harris systems.

A contract for the design of PTC will be issued in 1999, and a demonstration will be conducted in 2000, contingent upon continued FRA funding.

Overview of the Train Guard™

Train Guard™ was conceived in a Burlington Northern labor/management safety committee in early 1993 as a means to make train crew members aware of other trains in their vicinity in non signaled territory. Following the merger of the Burlington Northern and Santa Fe railroads, further development of the proximity warning system was assigned to the BNSF's Technical Research and Development staff which has vigorously pursued Train Guard™ development. The BNSF has retained Pulse Electronics to design and develop system.

Train Guard™ only has equipment on board the locomotive, and consists of an on-board computer (OBC), display, GPS receiver and mobile communications package (MCP) that transmits in the End of Train UHF bandwidth (450 Mhz). The OBC is provided with a track database that includes track curvature, grade, interlockings, signals, crossings and civil speed restrictions. The OBC uses GPS data, tachometer data and gyro data for positioning. Every 15 seconds, the MCP broadcasts the locomotive identification number, location, speed and direction. Transmissions received from other trains are displayed showing the other train identification, distance, speed, direction and time of the last radio communication received. The locomotive engineer is required to acknowledge the proximity of a new train, each signal location (not indication), and upcoming speed restriction. The OBC calculates braking distances to speed restrictions and initiates an automatic brake application if the train is not properly slowed or if the operator fails to acknowledge nearby trains.

Wayside communications networks are not required for Train Guard™ except in areas where MCP transmissions do not have coverage of 5 to 7 miles. In that event, wayside repeaters are installed to provide coverage of 5 to 7 miles. The broadcasts of the MCPs on locomotives and repeaters are open loop.

No central office equipment is required to support Train Guard™ though a means is being developed to digitally update on-board databases including temporary speed restrictions.

The BNSF is installing an Train Guard™ testbed between Barstow, California and Los Angeles, California, including a maintenance-of-way vehicle, to test Train Guard™ in the railroad environment. Train Guard™ is intended to be a low cost PTC system that fullfills the functionality requirements established and agreed to by the RSAC.

Overview of the Communications Based Train Management System (CBTM)

The CSX railroad has embarked upon the development of a PTC system identified as CBTM. CSX has retained Wabco to develop and test CBTM using the object oriented design concept and the CR/CSX/NS joint platform design. The CBTM design will be an open architecture.

CBTM will provide for the Railroad Safety Advisory Committee's (RSAC) core features in non-signaled territory: prevent collisions between trains; prevent overspeed of trains; and protect maintenance-of-way work zones from unauthorized intrusion by trains. CBTM will provide databases at wayside Zone Controllers that control train movements, issue movement authorities; issue targets for speed reductions, monitor switch positions; and protect maintenance-of-way work zones. The on-board computer (OBC) will calculate braking distances, calculate the far limits of authority, and initiate an automatic brake application at speeds above 5 mph when a violation is projected.

A testbed in non-signaled territory has been selected for testing CBTM concepts. The objective of CBTM is to design a system that meets the RSAC core objectives while providing an approach that permits the locomotive fleet to be economically equipped and interoperability achieved.

Overview of the Alaska Railroad Corporation Project (ARRC)

Early in 1998, the Alaska Railroad Corporation (ARRC) launched a program to install Precision Train Control™ (PTC) systemwide. The AARC PTC is a development of GE Harris, the System Engineer on the project.

The AARC PTC is a derivative of the UP/BNSF PTS project. Like PTS, PTC has three major segments: the Locomotive Segment; the Communications Segment; and the Server Segment, which requires support of a computer-aided dispatching (CAD) system. Unlike PTS, PTC will include a Track Forces Terminal (TFT) for roadway employees. The TFT will provide location and tracking of maintenance-of-way on track vehicles and digital communications for obtaining and releasing work zones for the protection of roadway employees.

The ARRC has completed installation of a communications system to support PTC. A CAD system has been delivered and is scheduled for implementation in the first quarter of 1999. Deployment of PTC is scheduled for the first quarter of 2000.

Emerging PTC Projects

Overview of the Norfolk Southern Location System (NSLS)

NSLS is recently emerging system for which specifications have not yet been completed or published. It is a proximity warning system that is being designed in-house on the Norfolk Southern railroad. NSLS is similar to Train Guard™ in that its concept is to inform train crew members about other trains in the vicinity.

NSLS will utilize transponders located at each signal location that provide information to on-board computers about the location, distance to and location of the next two transponders, maximum authorized speeds and civil speed restrictions. The on-board computer (OBC) will consist of an interrogator for reading transponders, a display and a mobile

communications package (MCP) for transmitting data from the OBC. NSLS utilizes a tachometer to determine position between transponders. When a train passes a transponder, the locomotive identification, location, speed and direction will be periodically broadcast in the Norfolk Southern's End of Train Device VHS radio spectrum. The VHS broadcast is expected to cover about seven miles. When another train enters or is within the coverage of a train, its identification, speed and direction will be displayed to the locomotive engineer and acknowledgement required. When two opposing trains identify the same second transponder in advance, a safe braking distance is determined causing the OBC to initiate automatic brake applications on both trains.

The Norfolk Southern is continuing to develop the design of NSLS, including possibly displaying signal aspects on the display. NSLS is intended to meet the PTC RSAC objectives.

Overview of the Industry/FRA/Illinois Department of Transportation (IDOT) Positive Train Control Project

The FRA instated this program jointly with the railroad industry and IDOT to design, test, build and install a PTC system on a segment of the Union Pacific railroad extending between Springfield, Illinois, and Mazonia, Illinois, a distance of about 120 miles. The railroad industry agreed to participate with the FRA and IDOT through the Association of American Railroads (AAR) and its subsidiary, The Transportation Technology Center, Inc. (TTCI).

The objectives of the project are to develop, test and demonstrate cost-effective and interoperable PTC system, including flexible block operations, and advance activation of highway rail grade crossing signals in a corridor with both freight and passenger service. In addition, the system must meet the safety objectives of preventing train-to-train collisions, enforce speeds and speed restrictions, and provide protection for maintenance-of-way employees and their equipment.

On July 15, 1998, TTCI issued a request for proposal seeking a System Engineer for the PTC program. The submissions of the offerors are being reviewed and a selection is expected to be made in October 1998. The project is projected to require four years to develop, test and demonstrate.

COMPARISON OF THE PTC PROJECTS

The ATCS specifications were developed by the railroad industry with participation by suppliers and the FRA. The intent was to provide for both interoperability across railroad control systems and interchangeability between supplier products for such systems. The ATCS specifications provided for a range of communications-based applications including, health monitoring, codeline replacement, work order reporting and positive train control to be hosted on the communications network. The specifications included standardized communications methods, train control messages, and the response to those messages.

The ATCS specifications provided for a modular approach to train control implementation. The railroads could build train control systems to meet the requirements for various operating conditions ranging from light density to heavy density lines. ATCS was not broadly enough based to include many of the systems and technologies currently being implemented, tested or designed.

A Matrix of PTC Systems (Appendix ___) identifies the characteristics of the systems in the 10 PTC projects. The matrix is composed of 14 categories containing data relative to each PTC system. Four categories, Architecture, Office Segment, Communications Segment and Locomotive Segment, identify the functionalities that set the systems apart from one another in terms of ~~puissance and~~ deficiency with regard to the safety of train operations.

The PTS, and ARRC systems will be centrally controlled from CAD systems while the ITCS, ACSES, CBTM, Train

Guard, NSLS, and NJT systems will be distributed systems even though installed in centrally dispatch systems.

Only one system, IDOT, has the objective to be a stand alone system. Three systems, ITCS, ACCES and NJT are integrated systems. Five systems, PTS, Train Guard, NSLS, ARRC and CBTM are overlay systems. The CR/NS/CSX project is a developing platform technology that will be utilized in the IDOT and CBTM projects.

The ITCS, ACSES and NJT systems are most potent from the perspective of safety of train operations. ~~(conclusion before analysis?)~~ These systems derive functionalites to enforce all train speeds and stop where stop is required from wayside signal systems that are designed and arranged to provide proper switch position, track and route integrity and spacing of trains. Protection of roadway workers is achieved by inputting work zone locations in databases on board the locomotive via transponders. The strength of these systems is integration with the wayside signal system where safety resides except for speed enforcement. The wayside signal indications provide a redundant overview to the locomotive engineer about the authority displayed in the locomotive cab. Further, the wayside signal systems provide immediate fall back to operations by signal indications in the event of failure of on board equipment. ACSES and NJT utilize proven technologies available off the shelf and, unlike ITCS, are not dependent upon an extensive communications network between trains and the control center or wayside. A weakness in the ACSES and NJT systems is ensuring transponder data is correct, especially in portable transponders used for the protection of roadway workers.

The PTS, CBTM and ARRC systems derive functionalities to enforce all train speeds and stop where stop is required from movement authorities issued to each train by CAD systems. These PTC systems require a communications network with high reliability and availability for transmitting and receiving data between trains and safety computers located in the central office or on the wayside. The strength of these systems lay in databases either on board or on the wayside that, in connection with GPS technology, provide precise train location for enforcement of all speeds and stop where a stop is required. Protection of roadway workers is accomplished by inputting the work zones and their associated speeds into the databases. In the CBTM system, the requirement for hard copy of block authorities provide a redundant overview of the authority displayed in the cab. A weakness of these systems is that in signaled territory, signal indications do not provide a reliable redundant overview of the authority displayed in the cab. The CBTM system does not enforce speeds or stop commands at speeds below 8 miles per hour. Except in traffic control territory, failure of the on board equipment in the PTS and ARRC systems will require fall back operations to copying and repeating mandatory directives for movement of the train.

The Train Guard and NSLS systems are proximity warning systems that derive functionality to prevent train-to-train collisions from the reception of data transmitted by other trains in the radio spectrum. They are locomotive on board systems extraneous to existing methods of operation or wayside signal systems, an irrelevancy (?) precludes enforcement of stop where stop is required, e.g., at the end of the limits of authority or a wayside signal aspect indicating stop. Wayside signal indications will provide redundant support of data displayed on board for the movement of trains but not for the protection of roadway workers. No such redundancy will exist in non signaled territory. The weakness of both systems is the dependence upon antennas on locomotives that may as a result of damage or deterioration unknowingly degrade transmission and reception of train location data in an open loop broadcast.

Benefits of Adding PTC to Existing Methods of Operation and Signal and Train Control Systems.

The initial concept of optional utilization of conventional signal and train control systems has evolved to development of PTC systems that augment existing wayside systems which still have many years of useful life. The current initiatives are to maintain the safety features and business benefits of existing systems while adding functions that cannot otherwise be obtained, particularly enforcement of all speeds and absolute stop where a stop is required. Such functions will reduce the human factors that contribute to train collisions, overspeed type derailments and casualty to roadway workers while providing for more efficient train management and track utilization.

It is evident that each current method of train operation and operation in each type or combination of signal and train control system is heavily reliant on human performance to properly issue and copy train orders, control train speeds and stop where a stop is required. PTC systems have the capability of systematically identifying the location of a train in relation to current speed requirements, speed restrictions in advance, and the point were a stop is required. The systems are capable of enforcing all speed limits and most will enforce all stop commands. Results of actual field tests of several PTC projects indicate that the systems have the potential to intervene before incorrect train orders or excessive speed imperil a train movement or a train passes a point where a stop is required.

PTC functionality of precisely identifying the location of a train provides the means for the protection of roadway workers. Inputting the location of work zones for roadway workers into the system affords roadway worker protection by enforcing train speeds to that prescribed for the work zone or, when necessary, enforce stopping before a train enters a work zone. This procedure will eliminate dependency upon train crew members to properly control the speed of a train in a work zone and ensure that a train cannot enter a work zone until authorized by the foreman in charge. The Train Guard and ARRC systems plan to provide tracking of on-track vehicles used by roadway workers. The Train Guard, NSLS and ARRC systems will implement a PTC terminal by which roadway workers can communicate with trains and the central dispatching office.

The application of any PTC system to the various methods of operation and wayside signal systems will elevate the existing level of safety for train operations and roadway workers. The centrally controlled systems have potential to achieve the most business benefits, e.g., traffic planning, train pacing, plant utilization, improved productivity in labor, fuel and equipment, etc. However, most PTC systems to some extent will provide means to achieve higher capacity in existing plant and certain economic benefits.

ITCS, ACSES and NJT systems are designed essentially to be installed where the method of operation is by signal indications to provide for closer headway of train movements at higher speeds. These systems will enforce the speeds prescribed by each wayside signal indication while safely permitting higher speeds than that for which the wayside systems were originally designed. The ability to increase train capacity without extensive plant expansion is of significant economic benefit, especially in corridors with limited rights-of-way. The ability to increase train speeds without modifications in the existing wayside system, also a significant economic benefit, improves throughput with resultant increased ridership on passenger trains and improved customer service.

The PTS, CBTM and ARRC systems are potentially capable of being installed in signaled or non signaled territories. Installation of these systems in signaled territory may or may not materially impact the existing method of operation except for enforcement of speed and stop commands PTS and ARRC systems will digitally transmit track warrant movement authorities to computers on board locomotives, eliminating the requirement of reading and repeating each authority which is both a safety and economic benefit. All three systems will promote expeditious handling of train operations by providing real-time information for better decision making. In non signaled territory, the systems will provide for closer headway of train movements with resultant increased track capacity.

The proximity warning systems, Train Guard and NSLS, are locomotive on board systems capable of being installed in signaled or non signaled territories. Neither system affects the existing method of operation nor do they require an extensive communications network for support. Train Guard is provided with an on board database and location system that precisely locates a train for speed enforcement. NSLS determines speed enforcement from data obtained from transponders located in the track structure and an on board dead reckoning system. However, a train equipped with either system will enforce all track speeds and safe braking distances between other trains or roadway workers detected within proximity capability of the on board communications system.

Wayside detectors monitor passing trains for defects, and conditions on the track or roadway that may affect the safe operation of approaching trains. Monitored defects may require immediate action or may require future maintenance. Wayside detectors may provide information directly to the train, to wayside signal systems or to remote systems (e.g. dispatch or other systems).

Examples of existing devices that monitor passing trains include:

- Hot bearing detectors
- Hot wheel detectors
- Flat wheel detectors
- Dragging equipment detectors
- High-Wide load detectors
- Truck performance monitors
- Acoustic bearing detectors
- Automatic Equipment Identification readers

Examples of devices that monitor wayside devices, track conditions or weather include:

- Switch position detector
- Track circuit/signal aspect monitor
- Slide detector
- Grade crossing warning system condition monitor
- High water detector
- Bridge integrity detectors
- High wind detectors

The objective of detectors is to report unsafe conditions and maintenance requirements. Coordination of these devices with a PTC system would appear to be an appropriate application of the technology, although not a core feature of PTC.

In present day operations, the communication link between detector and train is handled in many different ways, depending on the detector type, the host railroad and site-specific conditions. For example, hot bearing detectors are often equipped with "talkers" that transmit a voice message over the train radio channel to the crew, describing either an "all clear" status or the specific nature and location of the defect. Other types of train defect detectors may use a similar method, or may simply trip an alarm that sets the signal system to stop the train. In other cases the detector may transmit the information to a central monitoring point for support of maintenance decisions.

With PTC systems, the data link to the train may be used to deliver the information directly on-board for display to the train crew and/or automatic response by the train's on-board computer system. However, given the variety of different architectures of PTC systems currently under evaluation, the means to link the detectors themselves with the wayside-to-train communication link will vary with the PTC architecture in use. In some situations, it may be appropriate to provide a direct link between the detector site and the train. In other cases this may be inconsistent with the protocol of the wayside-to-train data link, requiring instead a "land-line" connection between the detector site and the source of wayside-to-train messages, whether that source be a central dispatch

facility or a distributed zone controller of some type that handles a somewhat more local area.

If the detector's link is to another ground-based facility, then the physical means to transfer the information may be optimized for any given situation, so long as the integration of the detector data into the train's authority message stream is consistent with interoperability requirements. There is still some value in having standards for the ground-to-ground communication link in terms of compatibility of different vendor products, but these benefits are unrelated to the application of PTC. If the link is directly between detector and train, then the detector site itself must be carefully designed and equipped to meet any pertinent interoperability standards. If PTC is coordinated with wayside detectors, maintenance, inspection, and testing procedures need to be explored.

Provided the data links have the needed capacity and do not introduce too much latency in the message delivery, the use of a PTC link for any of these detector applications has the potential to improve the timeliness of getting urgent safety information where it is needed. For example, in a wayside monitoring application, a rock slide detector could deliver its warning directly to the train, wherever the train is. In the typical current process of tripping a wayside signal when the detector is activated, if the front of the train has already passed the signal, there is no way to get the warning to the train. Conversely, if the train can respond, it will generally have to run at restricted speed for several miles with no clue as to whether the problem is an occupied track, broken rail, open switch, or rock slide. Also, identifying the cause of the alarm as a slide detection would give the crew a much better clue as to what to look for and pinpoint the location to the exact area of the slide detection device.

Latency and capacity concerns involved in message delivery time are an important design concern. Depending on many factors, the total time required to move a message from a wayside detector to the train needs to be as short as possible. Factors impacting this message latency time and capacity include the following:

Complexity of the path the message must follow from source to destination.
Competition with other messages that may be sharing various links in that path.
Competition for processor time at any node where the message must be handled.
Message prioritization in the overall communications architecture.
Capability of the ground-to-train link protocol to deal with unplanned messages under various loading conditions.

The system architecture must be carefully designed to assure worst case scenarios will not raise the latency to the point where performance becomes poorer than the independent methods in use today.

As electronically controlled pneumatic (ecp) braking becomes established in the industry, the need for wayside detectors to monitor for defects on trains may gradually be phased out. ECP braking brings with it an intra-train communication link that could support on-board defect detection on each car. At some point in the distant future, it may be feasible to expect all rolling stock to be equipped with devices to detect bearing problems, stuck brakes (a cause of hot wheels), flat wheels, and other mechanical defects. However, this is far enough into the future that there will be value for a long time in enhancing the wayside-based defect detection systems with improved communications through an interface with PTC.

PTC, ITS and Grade Crossing Safety

Overview

Of the 6,262[27] *US railroad accidents in 1997, 3,865 occurred at highway-rail grade crossings. These are the largest category of potentially preventable accidents that exist within the railroad industry. The reduction of these accidents has received significant attention from the railroad industry, federal, state, local agencies, and other private entities such as "Operation Lifesaver". These groups have worked cooperatively in many areas seeking to prevent highway rail grade crossing accidents. Railroads and public agencies currently spend $300 million annually to install, improve, and maintain highway-rail grade crossing warning systems.*

These investments have paid dividends. Although train traffic and highway vehicle traffic operating over highway-rail grade crossings has increased during the past few years, accidents at these crossings have decreased from 6,615 in 1988 to 3,865 in 1997.

The highway-rail grade crossing poses special challenges to the transportation community. It is an intersection of the railroad network with streets or highways, where the railroad has and must maintain the ultimate right-of-way (U.S. Supreme Court, Continental Improvement Company vs Stead). The failure of highway vehicle operators to obey traffic laws at grade crossings continues to be the most significant contributor to accidents, injuries, and fatalities at grade crossings. Further reduction of these accidents is a complex problem that involves a number of interrelated systems. While stringent enforcement of traffic laws and regulations will contribute to compliance with those laws, further reduction of these accidents can also be achieved through elimination of crossings, or the installation of active warning systems. Most highway grade crossings are equipped with either active devices (i.e. flashing lights and/or gates) or passive devices (crossing signs). Active devices are installed where the train and highway traffic justify the additional cost.

PTC technology provides the opportunity, in conjunction with intelligent transportation systems (ITS), to improve grade crossing safety. PTC provided data to ITS can support real-time information of train position and the estimated time of arrival at highway-rail grade crossings, and interactive coordination between roadway traffic management centers and train control centers. For example, remote monitoring systems could warn train control centers and/or traffic management centers of highway vehicles fouling the crossing and/or failures of active warning system equipment. PTC and ITS deployment may improve automated warnings at crossings and/or provide travelers with advanced warning of crossing closures. Just as highways and railroads intersect at grade crossings, the highway and rail information systems being contemplated can be made to interact, as well. The coordination of ITS with PTC systems at the grade crossing is an opportunity that should be anticipated and planned for.

PTC/ITS Applications

Several PTC and ITS pilot projects have been or are currently being undertaken in the United States, involving new technological applications which have the potential to further improve highway-rail grade crossing safety.

Minnesota Guidestar Project

One activity of this project is to provide in-vehicle warning to a highway user of an approaching train. The warning system is activated from the train occupying a track circuit. A small transmitter located at the highway-rail grade crossing broadcasts a message of an approaching train to receivers in highway vehicles. A warning is displayed to the vehicle driver on a dashboard display unit.

The wayside transmitter continuously transmits a low power frequency that can only be received near the vicinity of the crossing. When this transmission is received by a highway vehicle, part of the dashboard display unit is illuminated to show that the vehicle is approaching the crossing. The wayside transmitter transmits two conditions: *"**warning system activated" or "warning system not activated**."* When activated, a small model of the cross bucks and flashing lights is displayed on the dashboard of the vehicle.

The system is currently installed on school buses and tests that include the sensitivity of the receiver are being performed.

Michigan/Amtrak Incremental Train Control System (ITCS) Project (see also discussion in section III)

This project was undertaken in response to a FRA grant to test communications-based train control technologies for the operation of high speed passenger trains over areas not equipped with locomotive cab signals or train control systems. The ITCS has the ability to communicate with each grade crossing via data radio well in advance of actual arrival at the crossings. The communication requires the computer equipment onboard the locomotive to determine the "health" of the grade crossing while the train is still several miles away. ITCS verifies the following information:

Can the crossing warning system communicate with the train? If so, the train continues to proceed at maximum authorized speed. If not, the train must reduce to a

predetermined speed prior to arrival at the crossing.

Through a self-diagnostic process, is the crossing warning system prepared to operate as intended? If so, the train continues to operate at maximum authorized speed. If not, the train must reduce to a predetermined speed.

Has the crossing warning system been operational for five minutes or greater with no train present (false activation)? If so, the train will be restricted to a speed of 20 mph over the grade crossing because of the probability of highway users ignoring the activation of the warning system.

No information is displayed inside the motor vehicle.

Illinois Project (see previous discussion in section III)

New York State/Long Island Railroad "ATLAS" Project

The objective of this project, once implemented, is to provide a prediction of train arrivals to highway vehicles at crossings for traffic routing purposes. Crossing warning systems will be activated by radio transmissions from the approaching railroad locomotive. A display unit, mounted inside the cab of the locomotive, will indicate if there is a stalled vehicle on the crossing. The railroad's train control system has the ability to stop the train before arrival at the crossing if there is adequate braking distance for the train.

Los Angeles Metro Blue Line Project

This light rail transit project demonstrated the ability to detect highway vehicles on a grade crossing when the crossing warning system is activated by the approach of a train to prevent the lowering of four-quadrant exit gates until all vehicles have cleared the crossing. Vehicles are detected by inductive loops which are buried in the pavement under the grade crossing. The loops have worked well at detecting moving vehicles, but tests revealed one blind spot in which a small stationary vehicle could go undetected.

Pilot Study of Advisory On-Board Vehicle Warning Systems.

In May 1997, the Illinois Department of Transportation (IDOT) executed a consultant contract with Raytheon E-Systems to design, install, oversee, operate and maintain a demonstration system for a Pilot Study of Advisory On-Board Vehicle Warning Systems at Railroad Grade Crossings. IDOT is directing this pilot program that seeks to provide in highway vehicle warning systems of an approaching train.

Approximately 300 vehicles will be outfitted with the on-board system from Cobra Electronics as part of this pilot study. The vehicle mix will include a variety of ground transportation vehicles in the study area including:

School buses

Emergency service vehicles

(3) Commercial vehicles that are primarily housed in the study area

The system will use low powered communication transmitters located at the crossings that will be triggered by a train approaching or occupying the crossings. This transmitter will send a signal between 800-1,200 feet in all directions from the grade crossing and activate a receiver in any equipped vehicle within the range to alert the driver of a train's presence. The receiver in the vehicle will contain an audible, a visual, or a combination audible/visual warning. The pilot study area includes five grade crossings along the Metra-Milwaukee North Line equipped with detection and warning systems.

Mystic, Connecticut, School Street, Four-Quadrant Gate Installation

This installation is located on Amtrak's highway-rail grade crossing in the Mystic section of Groton, Connecticut. The system consists of four gate arms that fully block the roadway, preventing motorists from going around the gates. A special crossing sensor system collects and transmits information about the operation of the grade crossing warning devices to the cab of an approaching train at a point where the train will have time to stop before reaching the crossing.

In the event a vehicle is disabled or stopped between the gates, the advance warning system will activate signals in the train cab and stop the train. Exit gates are left in a vertical position until the vehicle is off the crossing.

North Carolina Sealed Corridor Project

This project's primary objectives are to determine highway-rail grade crossing warning system effectiveness, and using those outcomes to determine the systems needed to reduce risk. Highway median barriers, long gate arms, and four-quadrant gates were evaluated using video monitoring. In addition, video enforcement of grade crossing laws was instituted in Salisbury, NC. The results of the evaluation showed that a significant reduction in the risk of grade crossing accidents can be achieve with the installation of long arm gates, median barriers and four quadrant gates, and the enforcement of traffic laws using video cameras. Norfolk Southern and North Carolina DOT are currently implementing these systems from Greensboro to Charlotte, North Carolina.

Future Technological Applications (~~*This is a PTC report not a grade crossing report. Is this section too much for this report? Suggest a short statement on the ITS architecture, making the point that PTC can provide more information (data) on train location for use by ITS systems).*~~

The application of new technology at highway-rail grade crossings offers the future promise of:

higher levels of highway user and train crew safety,

greater warning system reliability and flexibility,

improved functionality and interconnection with highway traffic control systems and devices,

increased deployment of active safety devices.

An important consideration in planning for the future functionality of highway rail grade crossings involves compatible or even complementary developments in other sectors of the transportation system. One such complementary development pertains to ITS command and control systems which may improve the safety and efficiency of surface transportation systems. Using computer and communications technologies, many of the functions envisioned by advanced train control proponents are being adapted in ITS applications.

The design and implementation of an intelligent controller for ITS and PTC systems may serve as an effective vehicle to deliver accurate, timely, and critical information to highway users, as well as those responsible for managing urban traffic movements. Among the advancements envisioned with these dual developments in train control and ITS are:

additional means to detect the presence of trains which may enhance the effectiveness of highway rail grade crossing warning systems.

improved emergency vehicle dispatching and enhanced urban mobility through the provision of real time information on train activity.

in-vehicle signing or warning systems for highway vehicles and/or on-track vehicles.

improved interface with traffic management systems.

Potential applications include the following:

n In-Vehicle Warning System

In-Vehicle Warning Systems are intended to alert or warn a driver of a highway vehicle about the impending approach or proximity of a train. FRA has participated with the Federal Highway Administration and others in evaluating proximity warning systems for priority vehicles. Although exploration of technological options makes sense for the short term, it is not

clear that the inherent limitations of most current approaches can be overcome. Those limitations include:

Cost. Recovering the cost of train borne, wayside and/or vehicle hardware solely by preventing highway-rail crossing collisions seems unlikely. Although often deadly when they occur, these collisions are relatively infrequent considering the number of highway vehicles crossing at grade annually. The number of highway vehicles, crossings, locomotives and on-track equipment that would have to be equipped is staggering.

False warnings. Many concepts for in-vehicle warning would generate false warnings, because the system would not be able to discriminate real danger from mere proximity. In some systems, warnings would be provided to vehicles moving away from crossings and vehicles operating on parallel roadways. In areas of dense railroad operations, where risk is high, false warnings might be prevalent. False warnings will lead motorists to ignore or defeat the warning system.

"Uncovered" failures. Many of the ideas for in-vehicle warning systems, particularly those that are less expensive, would not be failsafe. Since existing warning systems work well *most of the time*, introducing technology that motorists may learn to rely upon--but is not fail safe--could actually degrade safety.

Integration of Positive Train Control systems with intelligent highway vehicles may ultimately permit presentation of a highly credible warning to a motorist approaching a crossing when a train is present or approaching. Such a system could reinforce the warning provided by automated warning devices at the crossing or -- where the train horn is the only active warning system at the crossing -- provide a more uniformly effective active warning at low marginal cost.

As an example, in order for one of the proposed systems to function properly and be affordable–

1) the transmission of adequate data would need to be a feature inherent in the PTC system;

2) the stream of information flowing to the highway side would need to be in a standard format;

3) the information would need to be transmitted to the vehicle on an ITS local frequency used for such purposes; and

4) in-vehicle intelligence provided for other purposes would need to be able to process the information.

This would require the highway vehicle to be equipped with a data radio receiver, a differential GPS receiver, a rail/highway database, a microprocessor, and appropriate software, together with the capability to provide an audible and visual warning. With the sole exception of appropriate application software, all of these elements will need to be installed on motor vehicles (particularly priority vehicles) in order to facilitate other ITS programs, such as warning of emergency vehicles approaching intersections.

The most immediately appealing approach to providing information from the rail side would be to broadcast train approach information in the affected area by simply declaring the identify of the train (by code) and time/position. If reliable, periodic transmission is practicable, the highway vehicle could then use the time and position information to determine the trains path and speed on the rail line. Alternately, the data package for each transmission could provide time, position, direction of travel and velocity. In either case the transmission would need to be sufficiently frequent to avoid insufficient warning (should the train accelerate) or excessive warning (should the train slow) approaching the crossing.

The system could be made more nearly failsafe if negative reports were required in each sector every five or ten seconds (depending on the size of the sector). Failure to receive such a broadcast when a highway vehicle is in the area of a rail line would trigger a prompt such as "TRAIN WARNING SYSTEM DOWN--USE CAUTION AT RAILROAD CROSSINGS."

Note that the stream of information flowing to the highway side would come from a data radio transmitter on the wayside. That installation would receive train position information from the central office or (acting as a zone server) from trains, handling the information required for a large number of crossings. This would be the most efficient approach, since a single train might be on a crossing and within 20-30 seconds of several other crossings at any given time. Broadcasting multiple messages containing the same information should be unnecessary. Managing this process to ensure timely reporting to the highway side is a major undertaking that must be considered as PTC systems are designed, verified and validated.

However, where appropriate, controllers used to process PTS/PTC information for active warning systems at a crossing might also be employed to generate messages for in-vehicle warning, as well. This information would need to be in the same format as information broadcast by sector.

Roadway Dynamic Displays

Dynamic displays include signboards and other visible information displays on the roadway that permit highway users to determine if it is prudent to traverse a grade

crossing. These displays might be implemented at either active or passive crossings. The following modes of operation would be at the heart of the system:

No train approaching crossing; **PROCEED:** Highway signal displays green "clear" indication, variable message sign is dark or displays "PROCEED" message.

Train approximately 60 seconds from entering crossing; **CAUTION:** Highway signal displays yellow "caution" indication, variable message sign displays "TRAIN APPROACHING FROM RIGHT/LEFT" and "## SECONDS TO ARRIVAL" messages.

Train approximately 20 seconds from entering crossing; **STOP:** Highway signal displays red "stop" indication, variable message sign displays "STOP" message. Remains in effect until the train has cleared the crossing.

While the above application has been recommended by the NTSB, there are many limitations which are inherent to the system and/or could provide a reduced level of safety from systems currently in use.

There are however, some dissenting viewpoints toward the use of such displays. In the United States we recognize a pair of flashing red lights to mean that a train is approaching a highway-rail grade crossing. This system has been in use and accepted since the 1920's, and it is incorporated in federal and state statutes. Providing a means of informing the highway user of the approach of a train, with devices other than flashing lights, may conflict with and detract from the instinctive reactions that the highway user has developed from life experiences. But equally important are the considerations that these alternate devices introduce. Dynamic message boards usually contain a written message. Should that message be only in English or multiple languages? How do we provide for the illiterate? Should we provide highway users with enough information to allow them to estimate if there is enough time to traverse the tracks before the train arrives; i.e., should we provide the time remaining before the train arrives? How should driver/pedestrian error be addressed? Currently railroad companies and employees are often held liable for driver/pedestrian non-compliance with existing warning systems. This is a concern that needs to be addressed in any new signage regulations.

In summary, flashing red lights are simple and well understood. Alternative warning devices may have a negative effect on safety.

Intrusion Detection

Provide description of proposed application. Early detection of stalled, disabled, or trapped vehicles blocking a crossing could potentially be accomplished by video image processing. This could permit a train to be stopped or slowed to restricted speed in anticipation of the blocked crossing.

Technologies currently being investigated for such an application include video imaging, radar, laser scanning and inductive detection loops. Train braking distance would determine the minimum distance from the crossing at which successful intervention in the train's operation would avoid collision with a stalled, disabled, or trapped vehicle. If a collision could not be avoided, intervention could still possibly reduce collision severity.

One major concern with this application is the possibility that motorists would learn to misuse this protective feature to intentionally cause trains to slow or stop by parking vehicles on the crossings. This might be done purely as vandalism or might be used in conjunction with criminal activity, such as theft of contents on stopped trains. Certain areas in the country have a real problem with this today, and the implementation of this system could provide an easy means to cause train stoppage, further compounding the problem. This misuse could also lead to increased delays for rail and highway traffic flows.

Remote Warning System Health Monitoring

A remote monitoring system could notify such personnel as the railroad dispatcher, signal maintainer, local police, and appropriate roadway authorities of a malfunction of the crossing warning system so prompt action to repair the system and/or warn highway users of approaching trains can be achieved.

Remote monitoring can provide secondary benefits to highway traffic operations personnel. A highway traffic management center (TMC) could determine the activation status of crossing warning systems, permitting the TMC to track train movements and take action to alleviate the effects upon traffic congestion on intersecting and adjacent roadways. Possible responses might include temporary adjustment of traffic signal phasing and timing and the implementation of lane use and turn restrictions through dynamic lane assignment and variable message signs. The information could also be relayed to police, fire, and ambulance services, to facilitate routings to avoid blocked crossings.

ITS USER SERVICE #30 Highway Rail Intersections (HRI) ***(don't know what this section adds)***

There was an initial noticeable absence of railroad issues (such as the highway-rail grade crossing) being included in the development of the ITS architecture. With the inclusion of User Service #30, the importance of the highway-rail grade crossing (or highway-rail intersection) as an ITS traffic control element was recognized, and the way was opened for much broader railroad participation. An important long-term solution to reducing collisions between highway and rail vehicles at highway-rail grade crossings will be through the use of ITS, that is, when intelligent systems will be able to alert the highway user to the presence of a train and decrease the probability of highway vehicle incursions into the right-of-way of an approaching train.
The ultimate objective of the ITS in-vehicle warning system program is to design a system to warn motorists about the numerous dangers, congestion and road blockage along the roadways, including the proximity of emergency response vehicles, the presence of school buses, and advanced warnings of approaching trains. This multiple functionality will allow motorists to avoid hazards and utilize alternate routes. In developing such devices, both the highway and railroad industries need to participate and coordinate their efforts in standards development committees. The National Transportation Safety Board (NTSB) recently encouraged the development of ITS applications (*R-98-41,-42*) and strongly urged the active participation of the railroad industry in all aspects of the standards development process.

The NTSB recommended that the DOT establish a timetable for the completion of standards development for ITS applications at highway-rail grade crossings and act to expeditiously complete those standards. There is a need for the establishment of national standards for such things as: radio frequencies; auditory alerts; message codes; ITS protocol; all communications that affect the grade crossing; and procedures necessary for maintenance, inspection and testing of ITS systems. DOT is providing technical assistance and financial support for the development of ITS standards by the national standards development organizations. As PTC is coordinated with highway-rail grade crossing warning systems, as with liability, procedures for the necessary testing, inspection and maintenance will need to be explored.

Recommendations

In order to promote the development of PTC and ITS systems that work in harmony, the RSAC recommendations are:

- Through the Illinois PTC Project, the railroad industry should work to describe feasible, effective and standard means of communicating train location, direction and speed to highway users (ITS User Service #30).
- The FRA should continue to work with the ITS program to ensure that standards are developed for User Service 30, including appropriate interfaces between PTC and Intelligent Transportation Systems.
- The Federal Highway Administration and ITS America should be encouraged to foster deployment of in-vehicle systems capable of appropriately utilizing data provided through PTC or other systems to warn motor vehicle drivers of the need to yield to trains at highway-rail grade crossings.
- The FRA should promote prudent research and development to enhance the potential for ITS and allied technologies to advance safety at highway-rail grade crossings by other means, such as warnings to trains of crossing system malfunctions, and detection of large vehicles improperly occupying crossings.

Risk reduction potential

A 100% risk reduction cannot be assigned to any individual risk countermeasure. There are risks associated with the adoption of any new technology. Some risks are uncovered because of cost, or system design. Other risks occur because of mistakes made in the implementation. Achieving safety is a combination of risk reduction strategies, targeted at specific safety concerns. Trying to address all possible risk areas leads to an inability to ever settle on the system requirements. It is better to address the primary risks and achieve incremental safety improvements.

A: Accident Statistics Review

A large accident data base of candidate PTC Preventable Accidents (PPAs) was reviewed by an Accident Review Team (ART) composed of RSAC members, and a judgment made on whether each accident was a PPA or not. These judgements were based on the generalized capabilities of the four PTC concept levels as discussed in chapter 2.

The Accident Review Team reviewed accidents from a data set of about 6400 accidents. This data set was compiled from over 25,000 accidents reported to the FRA from 1988 through 1997. The 6400 accident data set was reviewed in detail and the results of that review are shown in this report.

A review of the requirements for reporting accidents identified 63 causal factors of accidents that are potentially PTC preventable. The RSAC PTC Working Group assigned a team to identify the PTC preventable accidents in which those causal factors were present. The accident review team was composed of representatives from railroad management, labor and FRA and had many years' experience in railroad operations, signal and train control systems and research and development. In some cases, members of the ART Team were on site at the time of the accident investigation.

In its review of many reports, the Accident Review Team had ~~considerable difficulty~~ some problems in properly concluding what happened because data fields were in conflict, missing, insufficient or contained incomplete information. When necessary, further information was obtained from other sources. In every case, a final decision on the classification of an accident was achieved by consensus.

The determination that an accident was a PPA, a non PPA, or some other category resulted in a notation being made in the data base, under the appropriate design concept. Certain accidents were identified that: might be preventable by that category of PTC; may/will have the cost of the accident mitigated by a category of PTC; involve a track machine collision with another track machine that is not preventable with current technology but may be preventable with future technology; or involve collisions between trains and track equipment outside the limits of the track equipment's authority. The following symbols were used to identify the capability of PTC to prevent or mitigate accidents and are noted under the four PTC design concepts.

Y - Preventable by PTC

N - Not preventable by PTC (not included in the table)

M - May be preventable by PTC under certain circumstances

R - PTC will mitigate the cost of the accident

S - PTC may mitigate the cost of accident

W - Track machine collision with another track machine - not preventable with current technology

O - optional protection from collisions with trains when the track equipment is outside the limits of the track equipment's authority

The Accident Review Team completed an evaluation of about 6400 accidents that were determined from previous analysis to be "likely" PPAs. The result of that analysis is shown in Table 1. At each level there are a portion of the 6400 accidents that are PPAs, and a portion that fall into the categories of m, r, s, w, & o.

Table 1 PTC Accident Summary

Level	PPAs(y)	Category m	Category r	Category s	Category o	Category w	Total28
4	685	259	1	7	23	65	952
3	627	26	0	5	14	15	658
2	568	19	0	3	14	15	590
1	393	82	0	0	14	15	475

The m, r, and s categories represent some diminished risk of a PTC accident, rather than absolute "prevention." The o and w categories represent a potential future capability to prevent collisions between track equipment working under the same authority, and should not be considered to have any risk reduction due to PTC as defined.

An accident identified as category m or s in levels 1, 2, or 3 maybe classified as either a y or r at a higher level. An accident identified as category m in level 4, 3 or 2 may not be classified as a m in a lower level.

It should be understood that Table 1 does not represent the universe of PTC preventable accidents that occurred in calendar years 1988 to 1997, inclusive. Only a preferred number of accident cause codes were selected to identify candidate PPAs for review by the ART. It is probable additional accidents that are or may be PPAs reside under cause codes that were not reviewed by the accident review team.

~~B. Corridor Risk Assessment Model (CRAM) background~~

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In 1995 the FRA requested that the U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) determine the feasibility of developing a risk assessment tool for railroad operations based on a geographical information system (GIS) platform. The FRA was interested in using this analysis tool to determine if positive train control (PTC) could have measurable beneficial safety impacts on specific operational freight and passenger railroad corridors of the U.S. intercity railroad network. The Volpe Center determined that development of such a tool with GIS layers gathered from existing data bases of FRA track configurations, census population densities, etc., with added layers developed from inputs such as the Interstate Commerce Commission's waybill sample was possible. In 1996 the Volpe Center began work to build the GIS database and to conduct the related analysis effort. With the GIS data base, a definition of PTC preventable accidents provided by the FRA subject matter experts, an analytical model that described risk of PTC preventable accidents based upon geographical characteristics was developed. The preliminary results and conclusions were presented to the FRA and RSAC in June 1997.

When the RSAC PTC Working Group was formed in September of 1997 this effort was offered to the group by FRA as a possible tool to assist in their risk analysis. The Implementation Task Force of this Working Group was briefed on the background and status of this analysis effort, referred to as the Corridor Risk Assessment Model (CRAM). During late 1997 and into 1998 this Task Force and individual railroads provided input and direction to the ongoing modeling effort. Three areas of the modeling effort were addressed; 1) the definition and selection of PTC preventable accidents, 2) the data to be used as the basis for exposure measure - total train miles and million gross tons of traffic for each railroad; and 3) the definition of operational corridors that were to be analyzed. The Working Group formed an Accident Review Team (ART) that identified accident causes and specific accidents that could be used as input into the regression analysis for predictive purposes. The Association of American Railroads (AAR) and participating railroads, freight, intercity passenger and commuter, provided additional information on network flows of their respective operations.

Potential Future Uses of the Corridor Risk Assessment Model

The FRA plans to apply this new analysis tool to determine if a corridor approach to PTC implementation is appropriate, and as an evaluative tool for specific corridors. Several corridors in the U.S. such as Chicago to St. Louis, Chicago to Detroit and Seattle to Eugene are undergoing train control, operational and/or equipment changes as part of advanced train control and passenger equipment deployment efforts under the FRA's Next Generation High-Speed Rail Program. FRA wants to ensure that the risk potential in some of these operations is well understood and whether improved train control systems can reduce the risk at an affordable cost.

In addition the FRA intends to exploit the GIS platform of layered databases to conduct other studies of accident trends and safety enhancement measures for topics ranging from grade crossing safety to hazardous material movements.

Use of Regression Modeling to Predict Infrequent Events

Railroad accidents are rare events, on average only 1 FRA reportable train accident for every 264,000 train miles operated [FRA Railroad Safety Statistics - Annual Report 1997 - September 1998, Chapter 1, Page 1, Table 1-1]. Reporting thresholds in 1997 were $6,500 (this number is adjusted periodically for inflation) for rail track or equipment and any accident resulting in an injury or fatality. The subset of accidents that may be reduced by PTC is even less. However, PTC preventable accidents occasionally are of very high consequence with injuries and lives lost or major equipment damage. The CRAM was developed to support the analytical activities of the FRA's Office of Safety in this low probability but potentially high consequence arena of accidents. The Model was developed to determine what operational and track layout characteristics are statistically significant in PPA's and whether required implementation of PTC systems could reduce the accident risk potential on specific rail corridors. The model forecasts PPA's rates for defined corridors of the Class I intercity railroad network and the average consequences of those accidents.

Initially the accidents for study were determined by using a group of FRA accident subject matter experts to determine applicable cause codes and the degree of effectiveness of a PTC system to prevent accidents in these cause code areas from the FRA's (RAIRS) system. The data years 1988 to 1995 were used and the waybill sample was used to generate network flow data. These data layers resulted in the first model results known as CRAM I. The review of the 1988 to 1995 RAIRS data identified 570 accidents for historical plotting on defined corridors and 897 accidents for the regression analysis. Subsequently, the ART reviewed in detail each potential PPA in the 1988 to 1995 RAIRS database. This review resulted in 814 accidents for historical plotting and 617 accidents for the regression analysis. The new PPA's and network characterization data from the railroads was then added to the GIS platform and a second iteration of regression was done. The new model is referred to as CRAM II.

The theory behind both CRAM I and CRAM II is to estimate the safety benefits of PTC by relating the historic occurrence and consequences of accidents that may have been prevented by a PTC system to specific track features and traffic. The model as constructed will forecast the rate at which these accidents and their consequences were likely to occur. The model forecast does not account for any changes in operating rules or other structural changes (e.g. locomotive crashworthiness) that impact the occurrence and consequences of these accidents.

The determination of PTC system functions, and their effectiveness in accident reduction was made in conjunction with FRA Office Safety and independent subject matter experts under CRAM I and by a Task Force of the Implementation Working Group under CRAM II. The assumptions of what constitutes PTC systems is covered in Section III of this report. These assumptions were used by the Accident Review Team in their analysis of the RAIRS data. Both CRAM I and II are accident forecasting models to predict future patterns of PPAs based upon historical data. Analysis using both the predictive model, based on historical data in combination with significant operational and track attributes, and simple plotting of historical data has been developed. The main intent of this analysis was to determine corridors that are most likely to benefit from some form of PTC implementation.

Risk Analysis Framework

This risk analysis has included the estimation of both PPA probabilities and consequences. Certain system characteristics such as signaling and train control method, operational speed, track class, horizontal and vertical curvature, control points and number of tracks were studied to determine which ones had statistical significance relative to contributing to and thus aiding in predicting the probability and consequence of a PPA. To assess the risk impact of a PTC system three aspects of the accident occurrences are considered important; 1) accident location; 2) accident cause; and 3) accident outcome.

First, track and environmental aspects surrounding track as noted above describe the location of the accident are used as factors in the probability calculation. The accident rate is calculated based upon the characteristics of the rail network, and therefore the characteristics of track which promote the occurrence of an accident must be ascertained for the whole network.

Second, the cause of the accident determines whether or not it is included in the set of PPAs. Starting with FRA RAIRS accident cause codes the Accident Review Team developed the group of accidents for further study and is described in detail in Section IV B.

Third, the RAIRS database shows that PPAs were slightly more severe than the average accident, and as a result, only PPA accident outcomes were employed to develop the consequences portion of the model.

Geographic Data used for the Analysis

The geographical information system (GIS) used in this study facilitated the analysis of the rail specific characteristics in the prediction of risk and distinction of risk between corridors. This network thereby provided the basis for the accident rate calculation; the probability portion of the risk analysis.

For this study GIS data were gathered from the FRA 1:2,000,000 scale rail database, the FRA 1:100,000 rail database (developed by Oak Ridge National Laboratory for the FRA), and Volpe Center 1:2,000,000 and 1:100,000 rail databases. Detailed rail survey data available from a previous study was also used to add important attributes to the GIS platform. The resulting GIS platform is at a 1:100,000 to provide the required detail necessary for corridor analysis and consists of a fixed segment rail database that incorporates all the location-specific data from the various sources described above. Location specific data includes; switches, number of tracks, horizontal curvature, vertical grade, maximum speed, signaling system type, method of operation, route identifier, and population within certain distances from the track. This database consists of approximately 10,000 segments that are used for the construction of link-based calculations of risk and consequences. Links are defined in terms of control points as denoted by the presence of an interlocking switch. Link endpoints are also created at locations where Amtrak and commuter rail station stops are located, the number of tracks change, method of operation changes, or railroad owner changes.

Definition of Corridors

The first cut to define the corridors, generated 188 corridors with an average length of 325 miles. During the course of the RSAC, input from the owning railroads provided updates and refinements to these corridors. As a result the 188 corridors studied lengthened to an average length of 482 miles. These corridors represent the dominant freight and passenger routes in the United States.

Historical Data Analysis

Two methods for quantifying the potential risk reduction from PTC systems were used in this analysis. The first was to calculate the historical consequences of PTC preventable accidents and to assign those consequences to corridors. Using this method provides a straightforward description of the historical costs of accidents that could have been prevented by PTC. However, this historical methodology is limited in that the analysis fails to describe the factors that contribute to risk, or to provide a basis for describing future effects.

The Accident Review Team provided the Volpe Center with a more up to date list of Positive Train Control preventable accidents for the years 1988-1995. The ART identified 819 accidents that were PTC preventable (yes category) or partially preventable (maybe, r or s categories) using the highest (level 4) PTC system. Collisions accounted for 247 of these accidents, in which 51 people were killed and 449 were injured. The level 3 system, which assumed a lower level of functionality of PTC systems, was thought to have been able to prevent or partially prevent a total of 543 accidents, 231 of them collisions. Interestingly, these collisions included the same number of fatalities, and accounted for 443 injuries. At the PTC preventable levels 2 and 1, the total number of accidents classified were 478 and 384, and the number of collisions were reduced to 219 and 200. However, even at the lowest level of PTC functionality the total number of fatally injured in collisions remained 51. The level 2 system was thought to have potentially prevented 423 collision related injuries, and the level 4 system 400. This outcome does reinforce the perception that most fatalities and injuries are the result of collisions, which PTC at any level is designed to address.

Derailments are the second general category of accidents thought to be addressed by PTC. Derailments accounted for 423 of the 819 (52%) accidents at the highest PTC level, and dropped to 199 (37%) of the 543 accidents in level 2. At levels 3 and 4 they represent 32% and 28% respectively.

Other accidents (not collisions and derailments) are included in the group of PTC addressable accidents, including those involving maintenance of way workers and equipment. At PTC level 4, 149 accidents were thought to be preventable or partially preventable, accounting for 4 fatalities and 7 injuries, this number dropped to 113 for level 3, representing 2 fatalities and 5 injuries, 105 for level 2 and 75 at level 1 which includes 3 fatalities and 5 injuries.

The trends in the derailment category indicate relatively infrequent low-consequences events, whose greatest potential hazard is in the possibility of the release of hazardous chemicals requiring an evacuation. Eleven derailments account for 5300 to 5835 of the total number of evacuations and six collisions account for 1314 to 1334. One derailment, included in the group of accidents thought to possibly preventable by the highest level of PTC system, accounted for 50 fatalities. This accident is not consistent with the general trend of the consequences of PTC-preventable derailments being less than collisions, but it identifies a source of risk. The historical data can only answer part of that question. To understand the total risk potential for the U.S. that might be addressed by PTC, a more formal assessment of the hazards other than CRAM would be required.

CRAM II Results

A regression analysis is generally used to understand how different factors describing a system relate to one another. Since this analysis focused on the identification of locations where PTC preventable accident risk was significant enough to warrant implementation, the methodology was designed to identify characteristics of various locations that seemed to contribute to risk. The quantification of the contribution to risk of factors such as control methods, signaling, speed limits, the number of tracks and characteristics of the volume of passenger and freight traffic on the network were used to develop a tool that would make distinctions between corridors based upon PTC preventable accident risk.

Models were estimated using a regression methodology that allows the dependent variable to be the number of PTC preventable accidents that happened at a location. The independent variables used to understand the frequency of these accidents were the total million gross tons at the location, the curvature, switches, number of tracks, type of control method, and speed at the location. Models were estimated for all four levels of PTC preventable accidents, and subsets of collisions and derailments. The results of the model can be used to create a prediction for any location where there is complete data on these independent variables, provided the conditions represented by the model remain the same, and the accident trend on each corridor for the years analyzed is constant.

One of the most important components of the analysis is the input data. In this analysis, the critical variables, namely, the selection of PTC preventable accidents, and the freight flow data and the passenger flow data, were provided by the railroads. Network variables that describe track characteristics, control methods and speed, were collected from published railroad descriptions, track charts, schedules, etc. Some PTC preventable accidents occurred where freight or passenger flow had not been provided by the railroad. However, the railroads did provide that data on accident reports to the FRA at the time that those accidents occurred. In these cases, track density reported by the railroads on the RAIRS report were used in the analysis.

Using the highest level of PTC, the model indicates that the total freight flow, the number of tracks, and the number of switches and curves per mile contribute to increases in the expected number of accidents and that the presence of a train control method higher than dark but lower that automatic train control will reduce that risk. In addition, two other factors contribute to lowered risk, the average length of curves at a location and the average maximum allowable speed. Since the model is estimated by combining all of these factors to create an estimate of risk for a given location, it is most useful to apply the regression formula to each corridor and compare the predicted number of accidents for each one.

Accident rates were calculated for the 8 year period 1988-1995. The annual rate predicted per corridor is from .125 to 2.5 per corridor per year. Accident consequences vary by location and severity, depending upon whether both freight and passenger trains are involved, whether there is a hazmat release and the level of damage to equipment and track. Consequences for maintenance of way workers and equipment can be very severe from accidents that do not result in significant train or track damage. Therefore, forecasts of consequences must be made for individual accident types and severity.

If it can be assumed that accidents will behave in the future as they have in the past, then the historical consequences of accidents can be used to describe the likely consequences of future accidents. For this analysis, it is most useful to create a single unit with which to express risk. This is accomplished by quantifying the costs of accidents in dollars. Dollars are used to express the government's willingness to pay to avoid fatalities, injuries, track and equipment damages and evacuations. Using this methodology, costs were assigned to each PTC preventable accident, using the scale $2.7 million per fatality, $100k per injury, and $1,000 per evacuation. Dollar damages to track and equipment were inflated by .5625 to reflect additional unreported costs for repairs, delays and equipment damages. Using these numbers the average PPA cost $1.13 million, ranging from the lowest accident cost of $8,595 to the highest of $154,964,618 ($150M). Detailed results have been calculated for each corridor including the forecast number of accidents and expected dollar damages per accident. In the aggregate if a corridor is expected to experience from 0.125 to 2.5 PPAs per year, its expected PTC preventable safety benefits range from $141k to $2.8 million annually. (This needs to be corrected by the economics analysis team)

Each corridor has been ranked according to its historical accident costs, and its costs per mile and per ton-mile. Similarly, predicted corridor risks are ranked per mile and ton-mile. The results of these rankings are shown (in an appendix to this report). They indicate that the some corridors have significantly higher risk than others, but the majority of corridors are not significantly different from one another on the basis of risk.

Conclusions

~~In 1995 the FRA requested that the U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) to determine the feasibility of developing a risk assessment tool for railroad operations based on a geographical information system (GIS) platform. The FRA was interested in using this analysis tool to determine if positive train control (PTC) could have measurable beneficial safety impacts on specific operational freight and passenger railroad corridors of the U.S. intercity railroad network. The Volpe Center determined that development of such a tool with GIS layers gathered from existing data bases of FRA track configurations, census population densities, etc., with added layers developed from inputs such as the Interstate Commerce Commission's waybill sample was possible. In 1996 the Volpe Center began work to build the GIS data base and to conduct the related analysis effort. With the GIS data base, a definition of PTC preventable accidents provided by the FRA subject matter experts, an analytical model that described risk of PTC preventable accidents based upon geographical characteristics was developed. The preliminary results and conclusions were presented to the FRA and RSAC in June 1997.~~

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Historical Data Analysis

Two methods for quantifying the potential risk reduction from PTC systems were used in this analysis. The first was to calculate the historical consequences of PTC preventable accidents and to assign those consequences to corridors. Using this method provides a straightforward description of the historical costs of accidents that could have been prevented by PTC. However, this historical methodology is limited in that the analysis fails to describe the factors that contribute to risk, or to provide a basis for describing future effects.

The Accident Review Team provided the Volpe Center with a more up to date list of Positive Train Control preventable accidents for the years 1988-199531. The ART identified 819 accidents that were PTC preventable (yes category) or partially32 preventable (maybe, r or s categories) using the highest (level 4) PTC system. Collisions accounted for 247 of these accidents, in which 51 people were killed and 449 were injured. The level 3 system, which assumed a lower level of functionality of PTC systems, was thought to have been able to prevent or partially prevent a total of 543 accidents, 231 of them collisions. Interestingly, these collisions included the same number of fatalities, and accounted for 443 injuries. At the PTC preventable levels 2 and 1, the total number of accidents classified were 478 and 384, and the number of collisions were reduced to 219 and 200. However, even at the lowest level of PTC functionality the total number of fatally injured in collisions remained 51. The level 2 system was thought to have potentially prevented 423 collision related injuries, and the level 4 system 400. This outcome does reinforce the perception that most fatalities and injuries are the result of collisions, which PTC at any level is designed to address.

Derailments are the second general category of accidents thought to be addressed by PTC. Derailments accounted for 423 of the 819 (52%) accidents at the highest PTC level,

and dropped to 199 (37%) of the 543 accidents in level 2. At levels 3 and 4 they represent 32% and 28% respectively.

Other accidents (not collisions and derailments) are included in the group of PTC addressable accidents, including those involving maintenance of way workers and equipment. At PTC level 4, 149 accidents were thought to be preventable or partially preventable, accounting for 4 fatalities and 7 injuries, this number dropped to 113 for level 3, representing 2 fatalities and 5 injuries, 105 for level 2 and 75 at level 1 which includes 3 fatalities and 5 injuries.

The trends in the derailment category indicate relatively infrequent low-consequences events, whose greatest potential hazard is in the possibility of the release of hazardous chemicals requiring an evacuation. (Six?) derailments account for 5300 to 5835 of the total number of evacuations and (two?) collisions account for 1314 to 1334. One derailment, included in the group of accidents thought to possibly preventable by the highest level of PTC system, accounted for 50 fatalities. (this was a maybe) This accident is not consistent with the general trend of the consequences of PTC-preventable derailments being less than collisions, but it identifies a source of risk. The historical data can only answer part of that question. To understand the total risk potential for the U.S. that might be addressed by PTC, a more formal assessment of the hazards other than CRAM would be required.

CRAM II Results

A regression analysis is generally used to understand how different factors describing a system relate to one another. Since this analysis focused on the identification of locations where PTC preventable accident risk was significant enough to warrant implementation, the methodology was designed to identify characteristics of various locations that seemed to contribute to risk. The quantification of the contribution to risk of factors such as control methods, signaling, speed limits, the number of tracks and characteristics of the volume of passenger and freight traffic on the network were used to develop a tool that would make distinctions between corridors based upon PTC preventable accident risk.

Models were estimated using a regression methodology that allows the dependent variable to be the number of PTC preventable accidents that happened at a location. The independent variables used to understand the frequency of these accidents were the total million gross tons at the location, the curvature, switches, number of tracks, type of control method, and speed at the location. Models were estimated for all four levels of PTC preventable accidents, and subsets of collisions and derailments. The results of the model can be used to create a prediction for any location where there is complete data on these independent variables, provided the conditions represented by the model remain the same, and the accident trend on each corridor for the years analyzed is constant.

One of the most important components of the analysis is the input data. In this analysis, the critical variables, namely, the freight flow data and the passenger flow data, were provided by the railroads. Network variables that describe track characteristics, control methods and speed, were collected from published railroad descriptions, track charts, schedules, etc. Some PTC preventable accidents occurred where freight or passenger flow had not been provided by the railroad. However, the railroads did provide that data on accident reports to the FRA at the time that those accidents occurred. In these cases, track density reported by the railroads on the RAIRS report were used in the analysis.

Using the highest level of PTC, the model indicates that the total freight flow, the number of tracks, and the number of switches and curves per mile contribute to increases in the expected number of accidents and that the presence of a train control method higher than "dark" but lower that automatic train control will reduce that risk. (you didn't model atc, so what does this mean?) In addition, two other factors contribute to lowered risk, the average length of curves at a location and the average maximum allowable speed. Since the model is estimated by combining all of these factors to create an estimate of risk for a given location, it is most useful to apply the regression "formula" to each corridor and compare the predicted number of accidents for each one.

Accident rates were calculated for the 8 year period 1988-1995. The annual rate predicted per corridor is from .125 to 2.5 per corridor per year. (normalize please). Accident consequences vary by location and severity, depending upon whether both freight and passenger trains are involved, whether there is a hazmat release and the level of damage to equipment and track. Consequences for maintenance of way workers and equipment can be very severe from accidents that do not result in significant train or track damage. Therefore, forecasts of consequences must be made for individual accident types and severity.

If it can be assumed that accidents will behave in the future as they have in the past, then the historical consequences of accidents can be used to describe the likely consequences of future accidents. For this analysis, it is most useful to create a single "unit" with which to express risk. This is accomplished by quantifying the costs of accidents in dollars. Dollars are used to express the government's willingness to pay to avoid fatalities, injuries, track and equipment damages and evacuations. Using this methodology, costs were assigned to each PTC preventable accident, using the scale $2.7 million per fatality, $100k per injury, and $1,000 per evacuation. Dollar damages to track and equipment were inflated by .5625 to reflect additional unreported costs for repairs, delays and equipment damages. Using these numbers the average PPA cost $1.13 million, ranging from the lowest accident cost of $8,595 to the highest of $154,964,618 ($150M). Detailed results have been calculated for each corridor including the forecast number of accidents and expected dollar damages per

~~accident. In the aggregate if a corridor is expected to experience from 0.125 to 2.5 PPAs per year, its expected PTC preventable safety benefits range from $141k to $2.8 million annually. (This needs to be corrected by the economics analysis team)~~

~~Each corridor has been ranked according to its historical accident costs, and its costs per mile and per ton mile. Similarly, predicted corridor risks are ranked per mile and ton mile. The results of these rankings are shown (in an appendix to this report). They indicate that the majority of corridors are not significantly different from one another on the basis of risk.~~

~~CONCLUSIONS~~

C: Approach to Safety Management

Rules and regulations

The Standards Task Force was adopted as a subgroup of the PTC Working Group in December of 1997 for the following purpose:

To facilitate the implementation of software based signal and operating systems by discussing potential revisions to the Rules, Standards and Instructions (49 CFR Part 236) to address processor-based technology and communication-based operating architectures.

The following task components were included:

Disarrangement of microprocessor-based interlockings. What testing or other procedures and functions need to be performed in order to guarantee safe operation of a railroad interlocking control system that has been disarranged and subsequently restored to continue operation.

Development of performance standards for positive train control (PTC) systems at various levels of functionalities (safety-related capabilities).

Development of procedures for introduction and validation of new (what?) systems.

The Task Force could also consider conforming changes to related regulations (e.g., 49 CFR Parts 233, 234, and 235), as appropriate. The FRA members of the Task Force felt that the most logical way to fulfill the task requirements was to revise CFR 49 Section 236 to accommodate the new technology elements, and safety requirements of software based signal systems. A Draft text of revisions to Part Section 236 was made available to all Standards Task Force members for that purpose. Some members of the task force felt that 236 was a detailed and prescriptive type of regulation not suitable for the complexity of the processor-based and software-driven systems to which these new regulations would apply. They felt that it was time to develop performance based standards using Mean Time Between Hazardous Events or an equivalent performance metric. (Is this a recommendation of the Task Force?)

Several presentations were made by suppliers, railroads, labor, and government to educate members of the task force regarding what is needed for development of performance standards that could be used to regulate software based systems. Recognizing the need to proceed with a representative safety critical assessment methodology for proof of safety of PTC and processor-based systems, the group tasked the University of Virginia (UVA) Center for Safety-Critical Systems to develop a representative Risk Management Tool Set. An interagency agreement to fund work to be performed by the University of Virginia was set in place. The work is expected to produce a risk measurement toolset for a safety-critical assessment process. A two-day seminar was given to the Task Force members by the University as part of this task. The development of this Risk Management Tool Set does not imply that other comparable methodologies could not be used.

Another area of investigation that the PTC RSAC Working Group is investigating how to identify PTC information that can be communicated to highway traffic control/information systems. A ITS (Intelligent Transportation Systems) subgroup was established jointly with the Standards and Implementation Task Forces. The report of that subgroup is included in this report.

Discussions within the Standards Task Force continue at the time of this report. There is significant difference of opinion on the details of a revised Part 236. The scope of the changes has been a concern to many.

Axiomatic Safety-Critical Assessment Process (ASCAP)

An Axiomatic Safety-Critical Assessment Process (ASCAP) is under development at the University of Virginia Center for Safety-Critical Systems as a mathematical proof that is solved as a large-scale statistical simulation. It demonstrates the proof-of-safety-critical compliance to quantified risk exposure benchmarks for railroad freight and passenger train lines, subject to a statistical confidence level. The safety-critical benchmarks are expressed as accident risk exposures, which are normalized as either freight ton or =train miles or passenger train miles that include variable train densities and average speeds. The risk exposure accident metrics are calculated as severity multiplied by the statistical likelihood of occurrence of an unsafe event, where a train is coincident in time and position with an unsafe event. Severity is defined as catastrophic, critical, marginal and negligible. Catastrophic is the loss of life and major assets, critical severity defines minor injuries and loss of major assets, marginal severity defines minor asset accidents and the negligible for incidental accidents.

The ASCAP mathematical formulation describes the capacity throughput performance of a train line as constrained by the safety-critical capability of the signaling and train control system to mitigate the hazards, which threaten the safe operation of the train line. ASCAP is structured as a large-scale train-centric hazard scenario statistical simulation that handles a train line of up to one-hundred trains that includes freight, passenger and short line trains operating in a complex multi-layered signaling and train control environment. The risk exposures are calculated for each train operating in the train line and combined to provide the risk exposure of the total train line. An important feature of ASCAP is the capability to calculate statistically unsafe events that do not result in an accident as defined by the risk exposure metric. With this capability, ASCAP can provide a quantification of the train line reliability, availability, maintainability and safety (RAMS) for each train-centric unit and the total train line. The multi-layered signaling and train control systems can include dark territory, continuous signaling, intermittent signaling and communication-based Positive Train Control (PTC).

The ASCAP model formulation includes definitions, generally accepted industry standards, axioms (assumptions), hazards to be mitigated, the safety-critical protocol that mitigates the hazards, the proof-of-correctness of the safety-critical protocol and finally the proof-of-safety-critical compliance to established quantified performance-based safety-critical benchmarks. A unique feature of ASCAP is the capability to include the railroad operating rules, dispatcher safety-critical behavior and the safety-critical behavior of the train crew. The operating rules, dispatcher, train crew, track segments, switches, signal and processor-based equipment are all defined as objects. The safety-critical behavior of each object is defined with the calculation of an unsafe failure rate, which is in response to injected hazard scenarios. The definition of all of the traditional railroad safety-critical appliances as an object-oriented paradigm allows a detailed description of the signaling and train control system safety-critical behavior.

The hazard scenarios are selected as the list of hazards for which the most complex level of Positive Train Control (PTC) is required to mitigate. ASCAP, by selecting the most complex PTC hazard scenario list, is able to make safety-critical assessments of any signaling and train control systems implemented by the railroads. ASCAP will first be implemented as a pilot program in collaboration with CSX to establish safety-critical assessments of dark territory operation, traffic control systems and communication-based train management. An important outcome of the collaboration will be the safety-critical assessment of a communication-based train management (CBTM) overlaid on to dark territory.

A wide range of analytical tools are used such as formal methods, fault modes effect critical analysis, Petri-nets, Markov models, fault injection simulations and statistical methods to establish confidence levels. The need to calculate millions of miles of train-centric operation subject to a statistical injection of hazard scenarios requires that ASCAP be formulated as distributed and parallel processing model which can be executed on supercomputer platforms.

D. ~~Proximity-based Train Control Systems~~Alternative Methods to Positive Train Control

There are several proximity-based train control system that address the core PTC safety issues; train collision avoidance, overspeed protection, and maintenance of way protection.

Train GuardTM (Pulse Electronics) and other similar proximity-based PTC systems are estimated to cost less than other PTC designs, in part because no additional ground infrastructure is required. Train Guard™ utilizes the existing EOT radio frequency for train to train communications, thereby saving the need for additional radio hardware and a central controller.

A low-level PTC system, such as Train Guard™, could be a building block that could be expanded incrementally to a full "advanced" train control system. Implementation of this type of system could be much quicker than the more elaborate PTC systems envisioned, which would yield benefits to the railroads immediately. Overspeed protection for each locomotive would begin as soon as it is equipped with the system.

Proximity-based systems can be interoperable between railroads regardless of type or size. Safety improvements could be seen across the nation in a much shorter time than that required for the more complex and expensive PTC systems. Of particular concern is the ability for the short lines to be able to afford PTC systems. Proximity-based PTC offers the opportunity for smaller railroads to have a low-cost system that will provide the protection that they need but also leave them

the money needed for other investments to reduce derailments.

V. Safety Costs and Benefits of PTC systems (***PTC Economic Team*** *[Lynn Jarrett, Milhon, French, Roskind - point of contact, Ditmeyer, Newman, DePaepe, Clifford, Labor Economist TBD, 2 representatives from APTA TBD, FRA Accident Investigative Person, ATK representative?])*Other Communications, Command and Control Requirements for the 21st Century

~~Commentary: The discussion of costs versus benefits should address the following points:~~
~~Neither costs nor benefits should be double counted~~
~~Systems built to achieve business benefits may offset some PTC costs (e.g., datalink), but the value of the benefits are not attributable to PTC.~~

Other communications, command and control requirements for the 21st Century: potential role for PTC systems

A. Efficiency-related attributes of available architectures

Communications infrastructure

Potential interface with CAD / traffic planners

Flexible blocks

Commentary: Need to look at GE-Harris report that addresses these features.

B: Implications for traffic, information and asset management, system capacity, service quality and profitability

Background

Signal and train control systems are generally justified by the need for an increase in capacity of train traffic over a route. Historically, Centralized Traffic Control (CTC) has been chosen to achieve the increase in traffic capacity. CTC, in conjunction with Computer Aided Dispatching (CAD) has been the standard on most railroads most recently, where Automatic Block Signals (ABS) was the standard before. There are basically three reasons why a train control system needs to be upgraded:

The load on manual dispatching is to high to run the required number of trains at the maximum track speed.
Long blocks of space have to be allotted to trains, limiting the amount of trains that can be travel over a given route over a given period of time.
The old train control system is technically obsolete.

New Technology

PTC systems, depending on their architecture, will increase the track capacity and the amount of traffic that can be handled. This generally also improves asset utilization of locomotives, rail cars and the track, allows for better service to customers and improves profitability. It also improves the efficiency of train service crews by reducing train travel times and speed. Lines, currently equipped with a train or traffic control system generate these benefits already. Some PTC systems architectures provide an overlay over the existing train control system already in place and the benefits are strictly limited to improvements in train safety. A stand alone PTC system could replace the existing train and traffic control system. Therefore the decision whether such a system would be chosen depends on the need for the replacement of the present infrastructure due to age, additional capabilities needed or other criteria. Most existing signaled CTC systems have block sizes of about two miles, which for heavy freight traffic allows fleeting of trains with close spacing at track speed. This spacing also allows for efficient passenger train operation because of the shorter stopping distances of these trains.

Moving blocks, which can be achieved with communications based train control may have some benefits on tracks where trains with significant differing train speeds operate. Slow moving trains would waste capacity on a route originally designed for faster moving trains, requiring longer stopping distances. Electronically Controlled Power Brakes (ECP) can achieve similar efficiencies as moving block systems because it allows operation of higher speeds within fixed block systems due to shorter stopping distances.

Should the existing train control system need to be replaced for economic reasons, then a level four system can be chosen with various architectures. The control logic can be handled by a central office system, replacing existing CAD's and office systems or by a distributed logic architecture where the logic is handled locally and possibly linked to an existing CTC office system. Both systems would be capable of moving block operation and either have new integral traffic management systems or use the existing ones. The decision whether to use a central office or distributed architecture is dependant on the investment needed in a communications infrastructure, the overall system reliability requirements, the ability to safety assure large scale safety critical office systems and the level of configuration management that is required for each system type. It is not expected that level four systems offer significant improvements over existing train and traffic management systems except for route segments where moving blocks can improve the *real* train capacity. Real train capacity requirement is defined as the actual time table required by the railroad's customers and present and projected traffic levels and not some theoretical capacity, which cannot be utilized. Railroads have so far not been able to identify many routes where moving block provides significant benefits over fixed block signal systems. It is anticipated though that a moving block PTC system would improve the capacity of track warrant controlled railroad and once the technology has been fully developed, it is anticipated that railroads would use the new technology, especially if the costs are equal or less.

Scale of Implementation Necessary to Return Benefits

Background

The key to the implementation of PTC is equipping a sizable portion of locomotives with train control units. Until a large portion is equipped, the old train control system has to stay in place. Running unequipped locomotives on a new system will degrade the operating efficiency. Overlay PTC type systems are not dependent on having a large number of locomotives equipped, since the underlying train control system is still in place. Equipped locomotives will merrily improve the overall safety of the system, which is maximized when all locomotives are equipped. PTC systems will change in architecture and technology applied over time and it makes good business sense to take advantage of those advances. Therefore the locomotive-based equipment has to be designed to a minimum interoperability standard. Since the basic functions that make up every PTC system will not change, they can be defined and made independent of technology.

Equipping locomotives and maintenance of way vehicles will be the most expensive part of the PTC system. Wholesale retrofit cannot be economically justified. Incremental installation of on-board units as new equipment is purchased or overhauled will eventually result in the majority of locomotives to be equipped. As the attached graph from the French National Railroad shows, safety benefits will be accrued with every locomotive equipped and every mile of wayside equipped. This probably is the easiest way to continuously improve safety and receive the benefits as the capital investments are being made. There will be cases where the amount of traffic over a route, the desire to maximize capacity or the need for a high level of safety will make it beneficial to accelerate the installation of PTC units to locomotives. The economics will drive the rate at which PTC systems are implemented. There may be cases where the implementation speed will be driven by increased risk, such as high speed passenger traffic.

Summary

Implementation of PTC systems will be driven by economics of the systems. Most systems generate safety benefits only. Others may have some other benefits in limited geographic areas with specific traffic requirements. Companies spend their capital where the most benefits can be achieved. For a railroad, most of the capital investment will improve safety and operating efficiency. PTC, like any other capital requirement has to compete for limited funds. This precludes equipping large sections of track with PTC at one time, but an incremental investment based on priorities driven by risk. These corridors may not necessarily be adjoining. Locomotives and maintenance of way vehicles will also have to be equipped incrementally, driven by risk and return on investment. Therefore a technology independent, interoperable on-board units is a requirement.

Safety Costs and Benefits of PTC Systems

E. Other than Safety Benefits

Executive Order 12866, *Regulatory Planning and Review*, states that "Federal agencies should promulgate only such regulations as are required by law, are necessary to interpret the law, or are made necessary by compelling public need, such as *material failures of private markets to protect or improve the health and safety of the public*." As presented in Chapter 5, the safety benefits of PTC, i.e., the enforcement of speed limits and movement authorities that help to maintain safe train-to-train separation distances and ensure the safety of track work crews, are substantial. The FRA recognizes, however, that safety benefits alone would not cover the costs of universal PTC installation. (need footnote here from Savage study to show that there is no market failure of the railroad industry relative to safety).

Safety is driving the FRA's efforts to accelerate PTC deployment, but the technology also offers economic benefits. Although private sector economic benefits can not be the basis for regulatory action, Executive Order 12866 states that, "in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits (including potential *economic*, environmental, public health and safety, and other advantages; distributive impacts; and equity)." Accordingly, when assessing regulatory actions to accelerate PTC deployment, private sector economic benefits are relevant.

The economic benefits of PTC, or the "business benefits," have been the subject of extensive analysis. The FRA's 1994 *Railroad Communications and Train Control* study made the following statements regarding the business benefits of PTC:[33]

As reflected in this report, ATCS offers significant potential business benefits to railroads with pertinent needs not otherwise addressed through alternative technology. These include fuel savings, better utilization of track and equipment (such as work order reporting, locomotive health monitoring, and traffic control), reduced wear on track and equipment, on-board

hot bearing detection, car/trip scheduling, more precise scheduling of employee deployment, reduced job stress for dispatchers, and better service for customers (such as more reliable schedules and decreased transit time). All of these potential benefits offer possibilities for additional cost savings and managerial efficiency through increased network intelligence and enhanced information flows. [p. 61]

In the long term, the development of an integrated and interoperable communications network, such as ATCS, which will produce safety benefits, is likely. Commercial needs are growing; high quality service is essential to market growth in many sectors as shippers increasingly demand precision with respect to both pick up and delivery schedules. The rapid increase in intermodal service using containers, trailers, and other intermodal options places a premium on higher average train speeds, which requires better use of plant capacity and increasingly competent signal systems (as reflected by continuing investments in new traffic control systems on high density routes). As service requirements become more demanding on railroad plant, equipment, and personnel, the business benefits of flexible, interoperable, communication based PTC should become more evident and more readily quantifiable. [p. 62]

Previous rail industry technological advances produced benefits that were also difficult to estimate; the benefits of dieselization far exceeded predictions. FRA believes that the benefits of a control communications system B or flexible networks capable of functioning as a single system B can be expected to exceed the modest expectations of those advocating individual subsystems. Investments in safety and efficiency can produce synergies that result in unexpectedly high returns. [p. 63]

As indicated previously, the application of PTC to all rail lines has not been shown to be cost-beneficial at present based on safety alone. Business advantages to the railroad industry from such universal implementation can be expected, but the specific extent and nature of such advantages will differ greatly, depending on the particular circumstances. [p. 63]

Railroads recognize the need to move in the direction of positive train control, but with limited exceptions, have not considered the necessary investments justified. For the near future at least, safety benefits will have to be accompanied by "business" benefits for PTC investments to make business sense for widespread application to freight lines. [p. 76]

A central communication-based approach to PTC remains the most likely path to safer train operations. In addition, that approach has the greatest chance of returning business benefits that can help pay for a portion of the communication infrastructure needed to support safety applications. Although the application of PTC on all rail lines would not be cost-beneficial at the present time based on accident avoidance, PTC is required for high speed rail service and may be warranted on heavily traveled freight lines as well. Implementation of PTC that is interoperable will facilitate more widespread realization of safety and other benefits. [p. 76]

On some major freight corridors, downsized rail plants are now straining to handle increasing volumes of intermodal freight movements, as trucking companies and international brokers recognize the value of rail as part of the intermodal team. If freight capacity becomes a limiting factor, the ability of the railroad industry to relieve pressure on congested highways and to serve the Nation's environmental goals may be compromised. [p. 77]

Railroads themselves have sought to measure the economic benefits of PTC since they first formulated the concept. In 1991, the Transportation Research Board (TRB), the Association of American Railroads (AAR), and the Railway Progress Institute convened a symposium on Advanced Train Control Systems. In the foreword to the TRB record of the symposium proceedings, Howard Moody, the AAR's manager of Advanced Train Control Systems, stated the following:[34]

> ATCS benefits are great, with high rates of return and with significant hard-dollar benefits such as fuel savings and improvement in locomotive reliability. However, there are also significant soft-dollar benefits such as improvements in quality of service. These soft-dollar benefits are difficult to justify, in part because they are difficult to measure. Another aspect of these systems

is the potential to provide options for additional benefits from as yet unanticipated applications developed as railroad managers become familiar with the technology. ATCS should not and cannot be justified on one application alone or on the safety benefits alone, but on an overall strategy to build on the early commercial applications and then to pick up the options. With the technical and financial risk involved, most railroads will use this building block approach to ATCS.

ATCS will require sophisticated integration with operations and information management systems. This is a very important part of any implementation strategy. ATCS also offer the potential to transform the industry to open up new ways to compete. In other words, ATCS may provide a competitive advantage to the railroads.

Also in 1991, the Harvard Business School published a case study describing Burlington Northern Railroad's (BN's) efforts to develop and analyze PTC.35 The case chronicles the history of the company's ARES (Advanced Railroad Electronics System) project, which included the testing and demonstration of a prototype PTC system developed by Rockwell on 250 miles of track in northern Minnesota. Excerpts from the case study relate the expectations of the ARES project staff:

ARES will allow BN to run a scheduled railroad with smaller staffs and more modest [capital] investments than current signaling systems. It will maintain accurate, timely information about train consists and locations. The results will be improved service, with higher revenue potential, and cost reductions. Another important benefit will be the elimination of train accidents caused by violations of movement authority.

The potential benefit of ARES is large but highly uncertain: Using the best information currently available, we estimated the gross benefit in the range of $400 million to $900 million, with an expected present value of about $600 million. This benefit should be weighed against a cost of approximately $220 million (present value). The benefits depend greatly on implementation success: The system design must be sound, a strong implementation plan must be developed, and functional groups across the BN system must be committed to using it to full advantage.

The case presented a summary of the primary benefits expected from ARES:

Increased rail operations safety results from constant monitoring of wayside signal and detector equipment.

Greater operating efficiency and improved customer service come from operating trains to schedule and handling trains that deviate from schedule, the results of improved traffic planning.

Improved safety and increased customer service come from real-time position, speed and ETAs for all trains computed continuously and automatically provided to MOW crews and other BN users through existing BN computer systems.

Improved dispatcher productivity results from automating routine dispatching activities such as threat monitoring, warrant generation, traffic planning, and train sheet documentation.

Higher effective line capacity is provided by accurate vehicle position information and automatic train movement authorization.

Improved MOW productivity results from improved traffic planning.

Improved business management is possible with accurate, current information about the status and performance of operations and equipment.

The study examined benefits in the following areas and estimates the present value of those benefits:

- fuel $ 52 million
- equipment $ 81 million
- labor $190 million
- trackside equipment and damage prevention $ 96 million
- enhanced revenues $199 million

TOTAL $618 million

To account for uncertainty in these estimates, the study calculated ranges of values for them and probabilities of achieving values within the ranges

The factors with the largest potential for delivering benefits are also the most uncertain:

- ARES' ability to improve transit time and
- The amount customers are willing to pay for better service.

Accounting for ranges and probabilities, ARES will make the following mean contribution to net present value for each corporate strategy:

- focused strategy $360 million
- base strategy $406 million
- expansion strategy $576 million

The probability of ARES earning less than 9% real after-tax rate of return is extremely small

Ultimately, issues surrounding the company's overall financial operations and restructuring resulted in Burlington Northern's decision in 1992 to not implement ARES.

In 1993, the TRB, the AAR, and the FRA co-sponsored a conference on Railroad Freight Transportation Research Needs. At that conference, Moody discussed the state of ATCS development in the railroad industry and summarized the business cases developed by the Canadian National and Burlington Northern Railroads: 36

C3&I [Command, Control, Communication and Information] systems are being implemented to improve railroad productivity, customer service, and service reliability. Although significant progress has been made, even greater progress is in store in the future as railroads take advantage of advanced computer and digital data communication technology.

Both the Canadian National and Burlington Northern Railroads have done extensive business cases for ATCS. The Association of American Railroads (AAR) recently updated those business cases and provided the resulting report to its members. Both business cases demonstrated good potential internal rates of return, about half achieved with hard dollar savings and half with soft dollar savings. The industry is currently examining the long-range case for ATCS, and the next steps to take.

ATCS train control is expected to provide the following benefits:

Reduced headways to allow for increased line capacity. Independent studies indicate that a 25% increase is possible
Improved service reliability. ATCS has the capability to allow railroad operations to recover from delays and to improve meets and passes
Fuel savings from train spacing
Improved safety of operations from the use of digital data communication of movement authorities and from the enforcement of movement authorities and speed limits
Reduction in track damage and derailments due to excessive speed and poor train handling
Improved equipment use
Reduced dispatcher workload from the use of digital authorities to replace voice authorities

Complementary systems include the following:

Car distribution
Yard and terminal management
Strategic traffic planner and service design plan
Automatic equipment identification
Motive power management
Crew calling
Wayside and vehicle-borne detectors
Grade-crossing health monitoring, and
Remote control of locomotives

A draft report prepared for the FRA in 1997 examined the costs and business benefits of PTC.[37] The report presented the results of a study to provide a preliminary estimate of the business benefits of PTC on short corridors. Following are excerpts from that study:

Five railroad corridors, representing a range of conditions, were selected for study of the business benefits that would accrue if PTC were applied in each corridor. Benefits were quantified in the following areas:

reduced yard and transit time from improved work order reporting

reduced maintenance hours and en-route failures from locomotive diagnostics

fuel savings

reduced cost from improved equipment utilization

higher revenue from improved customer service

Benefits due to improved equipment utilization and customer service accounted for approximately 45% of estimated benefits; benefits from fuel savings and locomotive diagnostics, another 47%; and the remaining 7% was due to work order reporting.

Benefits quantified in this study were enough to cover 40% to 90% of total capital and operating costs of PTC, depending on the corridor and on the assumption regarding the number of locomotives that must be equipped. It is likely that cost coverage would be considerably higher if longer corridors conforming more closely to major transportation markets were chosen for analysis and if other business benefits not quantified in this study were able to be quantified. This is true not only because of the additional benefits, but also because, as more PTC-equipped route miles are added, fewer additional locomotives need to be equipped per added mile.

Benefit-cost ratios range from 0.34 to 0.90 for the five corridors. Two corridors have B/C ratios of roughly 0.6, indicating that there are significant benefits present, although too low to warrant investment on a corridor stand-alone basis. It must be remembered that corridors are being evaluated in isolation, and that this is the most costly method of implementation.

At present, there are a number of major efforts underway to develop PTC systems. Burlington Northern Santa Fe (BNSF, the successor to BN) and Union Pacific (UP) conducted a joint test of Positive Train Separation system in Washington and Oregon. The system was developed by GE-Harris, a joint venture between General Electric Company and Harris Corporation. GE-Harris also won a contract to install PTC on the Alaska Railroad. Wabco (formerly Rockwell) is building a PTC system for CSX to test in South Carolina and Georgia, and Harmon Industries is testing an incremental version of PTC for Amtrak in Michigan. CSX and Norfolk Southern have a contract with Wabco to develop an interoperable on-board locomotive communications bus for PTC to be demonstrated in Virginia, Maryland, and Pennsylvania. Another effort, sponsored by the AAR, FRA, and the State of Illinois, got underway in the summer of 1998.

Besides preventing collisions, the current PTC development efforts of BNSF, UP, CSX, Amtrak, and the AAR are expected to achieve greater operating efficiencies. PTC is expected to generate fuel savings to the railroads by allowing them to improve operations and scheduling. PTC, by pinpointing train locations, would permit railroads to do better meet-pass planning, thereby avoiding traveling at higher than necessary speeds and unnecessary waiting. BNSF estimates that it could save $24 to $40 million per year in fuel costs by moving at more constant speeds rather than the current pattern of hurrying up and waiting.38

The operating efficiencies produced by PTC, by improving utilization of locomotives, could reduce the number of locomotives needed. UP averages 2,300 meets and passes a day. If the time required for these actions could be reduced by 5 minutes each, the railroad would realize substantial savings on crews and equipment. The company estimates that for every mile-per-hour rise in average speed, 200 fewer locomotives would be needed. At an average cost of almost $1.6 million per locomotive, a mile-per-hour increase in average speeds would save UP $320 million on locomotive costs alone.39 By similar logic, the size of the existing railcar fleet could also be reduced as a result of the operating efficiencies produced by PTC.

Summary

The ability to be able to better track and control the location of trains via the more precise location information and data radio links available from a PTC-type train control system, if exploited to optimize network flows, can clearly increase overall railroad network system capacity. In a published paper, GE-Harris notes that “[p]rimary savings will come from two sources: an increase in network productivity and an increase in dispatcher productivity.” 40 They state that in studies that utilized actual train data, application of PTC technology resulted in average speed increases of 15 to 35%. During these studies they included anomalies such as undesired emergency brake applications, and the average speed was used as a figure of merit due to its direct relationship to asset utilization. GE-Harris notes that these speed enhancements were realized even though the objective of the study was to minimize train operating cost rather than maximize average speed. Finally, the GE-Harris paper states that “[a]nalytical projects based on a broad range of studies indicate that 95% on time performance (± 15 minutes) can be achieved in most cases where the controlling schedule is derived from the movement planner and the traffic is being controlled by PTC.”

A document produced by the BN ARES project team in August, 1991, addressed capacity enhancement. BN noted that considerable effort was put into modeling the way the railroad would operate with ARES in place and that the results of their studies indicated ARES could deliver 20% reduction in turn around times for unit trains, 15% improvement in on-time performance for freight trains, a 50% reduction in missed connections, and several years’ delay in the need to add track capacity in bottleneck areas. BN goes on to note that it foresaw significant reductions in capital outlays for cars and locomotives and significant reductions in fuel consumption among other potential benefits of adoption of a control system with the attributes of ARES.41

Although the full impact of how a PTC installation will affect railroad operations is often debated the examples above show that detailed study of particular systems and potential

installations clearly point to real and significant positive impacts on the railroad's operation. The benefits of a PTC system can be taken through decreases in overall shipment transit time, increases in reliability of transit delivery times, or through higher system throughput. How a railroad chooses to take these benefits, and in what combinations and ratios, will depend on their individual business plans, the types and mixes of freight hauled, and the type of service they wish to provide to their shippers. Nevertheless, the benefits from reduced transit times, increases in system average speeds, and more consistent and reliable service can be achieved and can be quantified on a case by case basis.

Another way to look at potential savings, or benefits, from PTC capacity enhancements is to consider the alternative costs of increasing capacity through the more traditional means of line upgrades or expansions. A UP press release dated December 1, 1998, cited a cost of $88 million for the construction of 32-mile stretch of track in western Iowa, or $2.75 million per mile to construct Class 5 track where a mainline had been removed in 1965.42 Two other railroad line capacity upgrades in the last year cost $180 million for 108 route-miles ($880,000 per route-mile) and $ 220 million for 270 route-miles ($1.66 million per route mile). 43 44 These projects range from complete new mainlines on routes with preexisting high levels of signaling capabilities to sections of new mainlines on partially multi-tracked routes with less advanced signaling capabilities that needed to be augmented. Another point of reference is a cost of $568,000 per mile for construction of unsignalized yard track with 100 pounds-per-yard rail. 45 Clearly, adding capacity to railroads is not inexpensive. The UP notes that for their central corridor alone they plan to spend $856 million to expand capacity over the next five years. 46

Although physical upgrades and additions of another track offer significant capacity improvements, PTC can help squeeze additional capacity out of existing lines before the need for a step function increase in capacity is reached. Capacity improvement projects often include not just track additions but improvements to signaling systems, such as installing bi-directional signaling to single direction signaling. PTC installed on such a line will also be able to gain the same capacity improvement benefit without any added costs. PTC's contribution to line capacity improvement can range from significant for a poorly-dispatched single-track unsignalized line to probably only a few percent for a well-dispatched double-tracked bi-directional CTC-signaled line.

Numerous studies have addressed the business benefits of PTC and identified positive effects accruing to the railroad industry. Although it is difficult to accurately predict the full extent of the benefits, they appear to be substantial. As hardware and software costs continue to decline and railroad traffic continues to grow, the magnitude of the benefits should become even greater.

In spite of the vast number of studies outlining the potential business benefits of PTC and its predecessors, no large scale implementation has occurred, because there as yet has not been sufficent justification to make the investment. Studies, after all, are just studies.

VI. Development and deployment of PTC systems ~~(*RSAC Progress Report Group, [points of contact are Chuck Dettmann, Grady Cothen, and James Stem until team make-up has been determined])*~~

There are a number of critical issues facing the railroad industry in the development and deployment of PTC systems. Some of these issues relate to the technical, schedule, and cost risks associated with the development of this new technology; some relate to challenges associated with deployment and operation in a large, diverse industry; and others relate to national-level technology infrastructure necessary for PTC to be cost-effective and viable. These issues have to be viewed from three different perspectives – national, the railroad industry, and individual railroad levels.

The key PTC development and deployment issues at the national level are radio spectrum availability, and implementation of a differential GPS network that covers all areas where railroads operate. PTC will use radio datalinks between trains and wayside, as well as other applications, as part of the basic system architecture. Successful deployment of PTC will require that sufficient radio frequency spectrum (capacity) is available to the railroad industry, on a dedicated basis, to support the safety-critical communications that provides the backbone of a PTC system. Without clear radio channels, PTC cannot be deployed, even if the technology is proven to satisfy the necessary functional and safety requirements.

At the railroad industry level, the Illinois PTC pilot program, along with other pilot and testbed PTC installations, will lead to refinement of the PTC requirements and evaluation of candidate system architectures and technologies. The industry PTC program will also produce standards that define the detailed requirements for PTC functionality and interoperability. The Illinois High-Speed Rail corridor will provide a testbed for evaluating PTC technology for application to freight and passenger operations.

At the individual railroad level, railroads will use the PTC standards as the basis for specifications and bid packages to procure PTC systems. However, PTC cannot be installed overnight, and will not be installed on all operating territories. The fact that locomotives traverse different territories within a railroad, as well as different railroads, presents special challenges in supporting railroad operations, particularly during the period when PTC is being initially installed. In addition, the industry is preparing to undergo a major change in its radio infrastructure, presenting an additional system migration challenge. These challenges will require development of mechanisms to ensure interoperability of systems as locomotives move around the country, and to facilitate safe and efficient operations in situations where an unequipped locomotive (or a locomotive with a failed PTC system) is operating in PTC-equipped territory. Practical and safe deployment

of PTC will require that rules, regulations, and systems accommodate operations in a mixed mode of PTC and other means of train control.

The subsections that follow address these PTC development and deployment issues in more detail.

A. Railroad Logistical Considerations

Technology Challenges

There are a number of challenges associated with the implementation of PTC technology. These challenges include the underlying technologies of PTC systems, and deployment of PTC in the railroad environment. The technology challenges include:

Radio Data Link – The industry must develop a radio data link with the capacity and characteristics suitable to real-time, safety-critical train control.

Location Determination System – A location system must be proven to provide the train location accuracy, integrity, and availability to meet PTC requirements.

Displays – PTC onboard information display requirements must be defined to achieve interoperability, and technology must be selected that will meet the rigorous railroad operating requirements in terms of physical ruggedness and suitability to use by typical train operators.

System Integration – Integrating the complex hardware and software elements of PTC systems represents a system integration challenge. Functions and software are distributed between mobile and fixed platforms, and the definition of messages and control logic must be precise to ensure both safety and interoperability. Experience across many industries in recent years provides testimony to the difficulties in fielding reliable systems that include geographically-dispersed systems with complex software interactions.

PTC Design for Specific Risks

PTC systems being tested by different railroads have been designed to address the risks associated with specific corridors, traffic patterns, and operating environment. These systems all perform the core PTC safety functions, while their detailed designs reflect the operating requirements and safety risks of the corridors on which they are implemented. The flexibility of PTC to address these corridor and railroad specific needs represents a significant advantage of the technology. There is no universal, “one size fits all” implementation of PTC; systems must be implemented in a way that addresses the risks of specific corridors in the most cost-effective manner.

Core Infrastructure Requirements

Deployment of PTC systems will require either upgrading or new installation of a number of communications and information systems on individual railroads that complement the PTC hardware and software that will be provided by PTC systems suppliers. These infrastructure elements are discussed in another section of this report.

System Testing and Verification and Validation

PTC systems represent a jump in technology for the railroad industry and its suppliers. They will require extensive testing to ensure that they meet all applicable safety design criteria as well as perform the specified functions. PTC systems will contain large amounts of new software that is distributed among mobile and fixed processors, with landline and radio communications linking them. Extensive software testing, possibly including the use of simulators as well as factory and field testing, will be required to ensure that the software not only provides the basic functionality, but reacts safely when unexpected or unplanned events occur. PTC systems must be demonstrated to exhibit design characteristics that are suitable to the railroad environment in terms of reliability, maintainability, ergonomics, configuration management, and the physical requirements of shock, vibration, temperature extremes, and humidity. Verification and Validation (V&V) procedures and standards will be developed for PTC systems as part of the AAR/FRA/IDOT PTC program. Test procedures will also be developed for the system to be deployed on the IDOT corridor.

FRA System Approval

Many PTC system implementations represent a significant change in technology from current traffic control systems. FRA regulations that have been applied to the design, operation, and maintenance of existing systems are not all suitable for application to processor-based systems. The PTC RSAC Standards Task Force is developing new rules, standards, and instructions for consideration that are designed to apply to processor-based systems. There will be a number of challenges to all parties involved in the deployment of PTC systems – railroads, suppliers, labor, and the FRA – to apply these new regulations appropriately. Inevitably, changes in both PTC system designs and the new regulations will be required to adapt to the new technology.

Migration From Existing Systems

Implementation of PTC requires deployment of new systems without disruptions to rail traffic, without causing safety problems during deployment, and taking advantage of as much existing infrastructure as possible. The railroad supply industry will develop PTC systems that take advantage of existing product developments and existing railroad infrastructure. Just as the railroads cannot afford to implement PTC at a rate that cannot be cost-justified, the suppliers cannot write off investment in current product lines overnight to develop PTC systems. Migration from current systems and products to PTC systems is essential to making PTC deployment cost-effective and realistically achievable. This means that migration strategies to implement PTC capability in phases must be developed. Experience in deploying complex new systems like the air traffic control system has shown that "flash cutovers" do not work, and can cause more safety problems than they are intended to address. The starting point for migration to PTC differs by railroad and territories or corridors, as well as by supplier. This translates to variations in PTC configurations for some time, complicating achievement of many of the projected benefits of PTC and the return on investment required to justify PTC costs. Development of carefully planned migration plans from current systems and operations to PTC will have to be accomplished in concert with the development and test of PTC technology for achieving the projected PTC benefits.

Rate of Deployment

Once PTC technology has been developed and tested, and the regulatory structure has been modified to facilitate system approval, the rate of deployment of PTC systems will be determined by cost justification, availability of capital and operating funds, migration from existing traffic control systems and associated infrastructure, and availability of proven products from suppliers. Deployment of new systems, particularly those involving new technology, always takes time. Problems in system design and performance are to be expected, requiring parallel operation with existing systems for some period. PTC equipment has to be installed on geographically-dispersed wayside locations, and on locomotives that are in short supply and utilized to their capacity. The simple physical limitations of installing and testing the hardware and software will limit the rate of deployment of PTC systems, just as it does for military, air traffic control, and other high-technology systems.

Unequipped Trains

A complicating factor in railroad operations is that locomotives are typically not dedicated to a specific corridor or route. Locomotives are assigned as needed to address current operating requirements. This means that a locomotive equipped with PTC equipment will be in non-equipped territory part of the time, and that it will be necessary to assign non-equipped locomotives to operate through PTC territory. This situation will be most prevalent during the initial deployment stages of PTC systems. Rules will be required to support the operation of unequipped trains through PTC territory, and the PTC system design must be able to identify the presence of unequipped trains (or other unequipped vehicles) on the track and ensure safe operation.

Interoperability

Achieving interoperability between different PTC system implementations by different suppliers will require comprehensive definition of the interaction between diverse system elements. Standards will be required to define system functions, the logical interaction of these functions, the communications and messages between different subsystems (such as train to wayside), and the integrity checks necessary to ensure that errors are not made due to exchange of bad data, timing anomalies, data context ambiguities, accepting commands from the wrong source, and other logical inconsistencies. Defining PTC system standards that provide the framework for achieving interoperability requirements without restricting system implementation and technology innovation represents a major challenge. There is no "one size fits all" solution to PTC, yet interoperability of systems developed for different traffic corridors is a critical element to ensuring that systems are cost-effective as well as safe.

Training

Deployment of PTC systems will require the development and execution of new operating and maintenance training programs. The installation, testing, operation, and maintenance of PTC will encompass new technology, new rules and regulations, new procedures, and new operating practices. Successful implementation of these new training requirements will require cooperation between railroads, labor, and the FRA, and will impose new challenges on suppliers of traffic control systems.

System Configuration Management

Management of the configuration of processor and software-based systems represents an area of expertise, procedures, and tools that the railroads and their suppliers have only recently begun to gain experience. Standard practices for configuration management of processor-based system is in an evolutionary stage. Making changes to current-generation software and processor systems used in the railroad industry has proven to be very expensive. Railroad personnel are often not able to make software changes due to the design of the software, availability of expertise, or

commercial practices of the suppliers. In order for PTC systems to be cost-effective to maintain, to remain safe in operation over time, and to facilitate system expansion or enhancements, the industry must develop system configuration standards and practices that are appropriate to PTC or other safety-critical systems. The railroads are not alone in addressing this challenge. Activities are underway in other industries nationally and internationally to define configuration management standards for safety-critical software.

B. NDGPS – An Enabling Technology (This section is unedited)

Introduction and Summary

The Air Force designed the Global Positioning System (GPS) to be a dual use system to meet the needs of both the military and civil sectors. As a result, the GPS signal specification defines two services. The first is the Precise Positioning Service (PPS), which is for the military and select government users and has a horizontal accuracy of 22 meters. The second is the Standard Positioning Service (SPS), which is available to the general public and has a horizontal accuracy of 100 meters.

The Differential Global Positioning System (DGPS) is now available to marine users all along the U.S. coast line and throughout our principal inland waters. Under this system, differential correction signals are transmitted from fixed ground stations, at low frequency, for processing with raw GPS signals from a constellation of satellites to achieve accuracy in practice of 1 to 3 meters. Intelligence at the differential beacon site determines the variance (vector) between the beacon's true location and that determined from SPS data, and uses the information to broadcast correction data which is used by GPS receivers to enhance the accuracy of the location solution.

With an incremental expenditure of less than $35 million, sufficient additional transmitters (67) can be placed to provide redundant coverage of the 48 contiguous States and Alaska. This highly accurate position, navigation, location, and timing system will then be used by both rail and highway users, among others. Public, nationwide deployment of DGPS (operated, maintained, and integrity monitored by the federal government, and free of user fees), will be necessary if this system is to be standardized nationwide for all users. Private differential services do not offer high reliability, consistent protocols, and full land area coverage--attributes that are essential to interstate rail movements employing interoperable train control systems.

With leadership from the FRA, the Office of the Secretary of Transportation, and the United States Coast Guard, a National DGPS network will be deployed. Constructed largely from infrastructure being retired from national defense uses, that network will be an enabling technology for PTC and many other civilian uses.

NDGPS Deployment

As noted above, the Coast Guard is already deploying DGPS for harbor and inland waterway navigation. The 61 radio-beacon transmitters of the marine DGPS system will be in place and declared to have Full Operational Capability by March 15, 1999 at a cost of $17.2 million, plus $5.0 million in maintenance annually.

Currently, the Coast Guard's DGPS covers the Coast of the United States and navigable waterways of the Mississippi River. The system was designed to be fully compliant with the RTCM SC-104 and ITU-R M.823 domestic and international standards, respectively. In fact, 35 nations currently operate systems that are modeled after the U.S. Coast Guard DGPS, and are compatible with the RTCM and ITU standards, thus providing the basis for a seamless worldwide navigation system.

In January 1997, the Department of Transportation formed an interagency NDGPS Executive Steering Group and NDGPS Policy and Implementation Team to lead the implementation of the nationwide system. The NDGPS Policy and Implementation Team documented the requirements of many Federal and state agencies, evaluated alternative methods of providing differential corrections, documented benefits, and developed a cost-benefit analysis in accordance with OMB circular A-94. This work is documented in the team's *Nationwide DGPS Report*. Many public safety applications are identified in the report, including saving lives on the railroads and highways.

In an unprecedented level of cooperation among federal and state agencies and industry, the United States is now developing a Nationwide Differential Global Positioning System (NDGPS). The development of the NDGPS will leverage the Department of Defense's investment in the Global Positioning System and the Coast Guard's investment in the maritime Differential Global Positioning System to provide a cost effective navigation system. In fact, NDGPS will soon blanket the nation with the most accurate and most reliable navigation service the United States has ever had.

Expansion of the proven Coast Guard design will only cost $35 million to implement on a national basis. In fact, the net present value of the 15 year system life costs are only $68.6 million, while the life-cycle benefits are estimated in the range of $10.4 billion, yielding an impressive benefit-to- cost ratio of 152:1. The low cost associated with this project is to a large extent the result of an opportunity for defense conversion. Conversion of the Ground Wave Emergency Network (GWEN) sites that the Air Force is decommissioning into DGPS reference stations will save the Department of Defense about $6 million in GWEN decommissioning costs, and save the Department of Transportation about $10 million in NDGPS implementation costs, while providing improved facilities that are hardened against weather and other hazards. It is a "win-win" situation for the both the American taxpayer and the governments at the federal, state, and local levels. The passage of Public Law 105-66, Section 346 (October 27, 1997) provided both the authority and the funding to immediately begin installations.

Proof of Concept for GWEN Conversion

Since DOT's plan is to reuse the Air Force's GWEN sites as they are decommissioned, FRA asked the Air Force if a site could be removed from the network to convert it into an DGPS site as a proof of concept. The GWEN site in Appleton, Washington, was converted and activated in May 1997. This first DGPS site has been transmitting flawlessly since then. Moreover, the

efficiency of the 300 foot, reused GWEN antenna far exceeded initial expectations.

While a typical Coast Guard DGPS antenna is between 13 and 17 percent efficient, it was anticipated that the larger GWEN antenna would have an efficiency of about 35 percent. But the near perfect match between the antenna and the DGPS frequency resulted in an exceptional 51 percent efficiency. This means that instead of radiating 130 to 170 watts, which is the power delivered by a typical Coast Guard antenna, the converted GWEN antenna radiates 510 watts. The range of the Appleton site is 200 to 250 miles, depending on the terrain and ground conductivity.

The Appleton site has also been used as a proof of concept for the use of DGPS in the Positive Train Control system.

Background and Technical Detail

PTC applications demand better accuracy, integrity and availability than either the SPS or even the PPS services provide. The first augmentation system that could address these shortfalls is the Coast Guard's Differential Global Positioning System. The Coast Guard needed a radio-navigation system, which would provide better than 10 meters accuracy along navigable waterways of the United States to improve the safety of maritime traffic. The Coast Guard's DGPS uses a system of reference stations to provide range corrections and integrity checks to users up to 400 kilometers from the reference station. The range of the signal is a function of the transmitted power of the reference station, the ground conductivity, and the skywave propagation of the signal.

The reference station continually monitors all of the GPS satellites that are in view. Since the reference station is surveyed, its precise location is known. Using this known position, the reference station calculates a correction for each satellite that is in view. The users receive the GPS signals from the satellites and the DGPS corrections from the reference station. Applying the corrections to the satellite pseudo ranges gives the DGPS user an accuracy that is typically between 1-3 meters, depending on the distance the user is from the reference station. The accuracy near the reference station is approximately one-half meter, but the accuracy degrades by about 1 meter for every 150 kilometers in distance that the user is from the reference station.

In addition to accuracy, integrity is essential to the navigation systems. Integrity refers to knowing if the GPS signal can be trusted for a location solution. Unfortunately, it can take 2 to 4 hours for a GPS satellite which is operating outside the acceptable parameters to pass over a control site where it can be flagged as being out of tolerance. DGPS, on the other hand, continuously monitors the satellites and, if a satellite is so far out of tolerance that it cannot be corrected, the user is notified within 2.5 to 5 seconds. This "time to alarm" integrity is very important in safety-critical applications such as PTC.

In addition to the accuracy of 1 to 3 meters and the integrity time to alarm of 2.5 to 5 seconds, the DGPS will provide dual coverage nationwide. That means, anywhere in the country, corrections will be available from at least two reference stations. Thus, if an unusual occurrence eliminates the signal from one reference station, such as a lightning strike at one of the reference stations, or radio interference that jams one reference station, the other reference station will ensure continuous service. The percent of time that a service is available is referred to as operational availability. Since a single reference station is designed to provide an operational availability of 99.7 percent, dual coverage will provide an availability of 99.999 percent.

Role of DGPS in Train Control

Other Markets for NDGPS

Someday GPS/NDGPS receivers will be as common in cars as AM/FM radios are today. An integrated vehicle safety system consisting of a NDGPS receiver, collision sensors, and communications links can help prevent accidents and notify emergency personnel when an accident does occur. A collision sensor, similar to the sensor in an air bag, could automatically send a preformatted message over a cell phone to an emergency response center at the instant an accident occurs. The message would contain the exact location of the accident from the NDGPS position. No longer will an injured person have to wait for a Good Samaritan to drive by the accident, locate a phone, and call for help. The notification will be instantaneous. The emergency response team could use the NDGPS receiver to automatically plot the fastest route to the accident, taking into account the roads that are blocked by traffic. Thus, the notification time will be completely eliminated and the emergency response team's time will be greatly reduced. It is estimated that this could save up to three percent of the 41,000 people who die on U.S. highways each year, which amounts to 1,230 lives.

Similarly, a communications link from the emergency response center to cars equipped with NDGPS receivers could indicate where accidents have occurred. The NDGPS receiver could plot accident locations on an Electronic Graphic Display Unit and provide an audible warning to the driver as he approaches the accident. This warning of an accident a mile or two ahead could prevent multi-car pileups in poor visibility or icy conditions.

Many other Federal and state public safety requirements have been identified. For example, NDGPS could be used in search and rescue, fire fighting, oil spill response, monitoring shipment of hazardous material, and mapping contaminated water supplies. In fact, many of these functions are currently being performed using DGPS in areas covered by the Coast Guard's system.

In addition to the public safety applications, NDGPS will be used in a myriad of other applications including weather forecasting, precision farming, and surveying. The National Oceanic and Atmospheric Administration will use the reference stations of the NDGPS system to improve the Nation's weather models. The GPS satellites broadcast signals on two frequencies. These signals are delayed at different rates as they travel through the water vapor in the atmosphere. The more water the more the delay. The amount of water vapor in the atmosphere can be very accurately predicted by measuring the difference in delay between these two frequencies. This continuous, real-time water vapor information from all of the NDGPS reference stations will be fed into the Nation's weather models, improving the short-term weather forecasts.

In areas where the Coast Guard system provides coverage, farmers are using the signal to measure crop yields, apply only needed fertilizers and pesticides, and sample soil conditions. These applications are collectively known as "precision farming." Using NDGPS in precision farming increases crop yields and reduces pesticide and fertilizer use. The increase in yield increases the farmers' profits. The reduction in

pesticides and fertilizers not only saves the farmer money but it also reduces the run off of these chemicals into the environment.

Full deployment of an expanded U.S. Coast Guard differential GPS into a Nationwide Differential Global Positioning System (NDGPS) can significantly aid the development of positive train control systems by providing an affordable and competent location determination system that is available to surface and marine transportation users throughout the contiguous United States and Alaska.

PTC systems will require a location determination system that is more accurate than non-differential GPS. The NDGPS network will significantly enhance the utility of GPS for PTC applications. However, PTC pilot programs have shown that even differential GPS does not provide sufficient accuracy, with the required level of assurance, to determine which track a train is on. To address this issue, other sources of information about train location, assigned train route, switch settings, and train movement can be used to resolve train location ambiguities. However, differential GPS is a necessary starting point for these approaches.

One of the principal issues related to PTC is affordability. Differential GPS capability must be available throughout the national rail system and be compatible with interoperable PTC systems if affordability is to be achieved.

NDGPS will provide benefits to a number of other industries in addition to the railroads. Identification of the other markets for NDGPS and the cost reductions and societal benefits related to applications in these other industries are addressed in the box above.

Completing DGPS

The Department of Transportation and Related Agencies Appropriation Act, FY 1998, Public Law 105-66, Section 346 outlines the requirements and establishes the authority for DGPS. A copy of section 346 is included as Appendix **XXXXXX**. The law also provides $2.4 million, in fiscal year 1998, to begin the installation of the system. The FY 1999 Act continues funding, with an additional $7.5 million available for deployment of the system.

The DGPS system will be installed using commercial products and services and will be maintained through commercial services contracts. Thus, the DGPS program maximizes the use of commercial products and services.

As mentioned earlier, the NDGPS will reuse Ground Wave Emergency Network (GWEN) sites which the Air Force no longer needs. The Air Force has 53 operational sites and 6 spare systems. The program will reuse the 300 foot antennas, two equipment shelters and a 25KW generator at each site. Since DGPS coverage model predictions indicate that 66 sites will be required, it will be necessary to purchase some additional antennas, equipment shelters, and generators or battery backup units.

Unfortunately, not all of the GWEN sites are where they are needed. Thus, some of the sites will be moved to new locations. The plan calls for 33 GWEN sites in their current locations, 26 moved GWEN sites, and seven (7) new sites. The sites will be installed in two phases. The first phase will provide single coverage to the entire country. The second phase will provide dual coverage. Based on current budget constraints, the program will take four to five years to complete, but acceleration of the program is feasible if user needs require it and funding is made available.

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~~**Role of DGPS in Train Control**~~

~~Full deployment of an expanded U.S. Coast Guard differential GPS into a Nationwide Differential Global Positioning System can significantly aid the development of positive train control systems by providing an affordable and competent location determination system that is available to surface and marine transportation throughout the contiguous United States and Alaska.~~

New PTC systems will be communication-based. That is, they will depend upon use of data communication over a variety of paths, including radio, to gather information for integration by microprocessors. The positioning system for PTC will necessarily include train-borne elements or be entirely accomplished on board. The UP/BNSF PTS project has termed the automatic location element of their system the **Location Determination System (LDS)**, and that acronym will be used in the remainder of this discussion.

One of the principal issues related to PTC is affordability. If systems are highly affordable, they will be widely deployed for both safety and nonsafety business purposes. Wide deployment will mean that collision avoidance and other safety features will be available over a larger portion of the national rail system. Universal equipping of trains with on-board systems will be necessary to realize maximum safety benefits. LDS must be available throughout the national rail system and be compatible with interoperable PTC systems if affordability is to be achieved.

As noted above, the Burlington Northern Railroad and the Union Pacific Railroad jointly developed a pilot project to demonstrate a PTS system (a first-generation communication-based PTC system). The railroads and their suppliers have evaluated their requirements for train location in relation to the Coast Guard's DGPS system as follows:

- The single most stressing requirement for the location determination system to support the PTS system is the ability to determine which of two tracks a given train is occupying with a very high degree of assurance (an assurance that must be greater than 0.99999 or (0.95)). The minimum center-to-center spacing of parallel tracks is 11.5 feet. Direct GPS *will not* satisfy this requirement. The USCG DGPS radio tower beacon system, as a first level of augmentation, also *will not* satisfy this requirement. When viewed as a two dimensional area problem, it is unlikely that *any* economically feasible system could achieve this accuracy to the required 0.95 probability.

- However, fortunately, the nature of the train location problem is more *one* dimensional, with well defined discrete points (switches) where the potential for diverging paths exists. The USCG DGPS narrows the location to less than 10 meters (33 feet). The most frequent interval at which successive turnouts can be located (locations at which a train may diverge from its current route over a switch) is 48 feet. Since the train is constrained to be *located on a track*, as opposed to somewhere within an area, this collapses the problem from a two- or three-dimensional problem into a *one*-dimensional problem.

- The *detailed* track geometry data for a specific route are stored on-board the locomotive (needed for calculating the safe braking distance algorithm). Which of two parallel tracks a train is occupying can then be determined by maintaining a continuous record of which direction the train took over each diverging switch point (normal or reversed). There are several heading reference system techniques available to make this determination. (Within the UP/BNSF PTS project, an inertial systems (ring laser gyro) was demonstrated to be a successful augmentation.)

This analysis supports the utility of DGPS, supplemented by other techniques, to determine train location with a very high degree of confidence.

Benefits of a nationwide surface LDS would not be limited to freight and passenger railroads. Precise positioning creates the potential for highway-side benefits, as well, including systems that could provide enhanced warning for collision avoidance at highway-rail crossings. As in the case of PTC, additional expenditures would be required to realize these benefits. Those expenditures would have to be justified based on their merits and after appropriate research and demonstration.

NDGPS Deployment

As noted above, the Coast Guard is already deploying DGPS for harbor and inland waterway navigation. The 61 radiobeacon transmitters of the marine DGPS system will be in place and declared to have Full Operational Capability by March 15, 1999 at a cost of $17.2 million, plus $5.0 million in maintenance annually.

In an unprecedented level of cooperation among federal and state agencies and industry, the United States is now developing a Nationwide Differential Global Positioning System (NDGPS). The development of the NDGPS will leverage the Department of Defense's investment in the Global Positioning System and the Coast Guard's investment in the maritime Differential Global Positioning System to provide a cost effective navigation system. In fact, NDGPS will soon blanket the nation with the most accurate and most reliable navigation service the United States has ever had. But the system will be more than a navigation system. It will also be used in a wide array of other applications such as surveying, weather modeling and precision farming.

One might estimate that a system like that would cost billions to build, but the proven Coast Guard design will only cost $35 million to implement on a national basis. In fact, the net present value of the 15 year system life costs are only $68.6 million while the life cycle benefits are estimated in the range of $10.4 billion, yielding an impressive a benefit to cost ratio of 152:1.

The low cost associated with this project is to a large extent the result of an opportunity for defense conversion. Converting the Ground Wave Emergency Network (GWEN) sites that the Air Force is decommissioning into DGPS reference stations will save the Department of Defense about $6 million in GWEN decommissioning costs and save the Department of Transportation about $10 million in NDGPS implementation costs, while providing improved facilities hardened against weather and other hazards. It's a "win-win" situation for the both the American taxpayer and the governments at the federal, state, and local levels. The passage of Public Law 105-66, Section 346 (October 27, 1997) provided both the authority and the funding to immediately begin installations.

Background and Technical Detail

The utility of a worldwide navigation, positioning and timing system that is free of user fees led to the enormous success and acceptance of GPS. It also created a rapidly growing GPS industry. But as successful as GPS is, it is not accurate enough for some applications.

Many applications demand better accuracy, integrity and availability then either the SPS or even the PPS services provide. The first augmentation system that was developed to address these shortfalls is the Coast Guard's Differential Global Positioning System. The Coast Guard needed a radionavigation system, which would provide better than 10 meters accuracy along navigable waterways of the United States to improve the safety of maritime traffic. The Coast Guard also needed the improved accuracy of the system to more efficiently position the thousands of navigation buoys, which line the rivers and harbors of the United States. The Coast Guard's DGPS uses a system of reference stations to provide range corrections and integrity checks to users up to 400 kilometers from the reference station. The range of the signal is a function of the transmitted power of the reference station, the ground conductivity and the skywave propagation of the signal.

The reference station continually monitors all of the GPS satellites that are in view. Since the reference station is surveyed, its precise location is known. Using this known position, the reference station calculates a correction for each satellite that is in view. The users receive the GPS signals from the satellites and the DGPS corrections from the reference station. Applying the corrections, to the satellite pseudo ranges, gives the DGPS user an accuracy that is typically between 1-3 meters, depending on the distance the user is from the reference station. The accuracy near the reference station is about a half meter but the accuracy degrades by about 1 meter for every 150 kilometers in distance that the user is from the reference station. The real-time accuracy, from the DGPS reference stations, meets the accuracy requirements of a wide range of applications from maritime navigation to Positive Train Control to land navigation and to precision farming.

In addition to accuracy, integrity is essential to the navigation systems. Unfortunately, with GPS it can take 2 to 4 hours for a GPS satellite, which is operating outside the acceptable parameters, to pass over a control site where it can be flagged as being out of tolerance. DGPS, on the other hand, continuously monitors the satellites and, if a satellite is so far out of tolerance that it can't be corrected, the user is notified within 2.5 to 5 seconds. This "time to alarm" integrity is very important in land, sea and air navigation applications, where the safety of lives is at stake.

Currently, the Coast Guard's DGPS covers the Coast of the United States and navigable waterways of the Mississippi River. The system was designed to be fully compliant with of the RTCM SC-104 and ITU-R M.823, domestic and international standards. In fact, 35 nations currently operate systems that are modeled after the U.S. Coast Guard DGPS, and are compatible with the RTCM and ITU standards, thus providing the basis for a seamless worldwide navigation system.

In January 1997, the Department of Transportation formed an interagency NDGPS Executive Steering Group and NDGPS Policy and Implementation Team to lead the implementation of the nationwide system. The NDGPS Policy and Implementation Team documented the requirements of many Federal and state agencies, evaluated alternative methods of providing differential corrections, documented benefits, and developed a cost benefit analysis in accordance with OMB circular A-94. This work is documented in the team's *Nationwide DGPS Report*. Many public safety applications are identified in the report, including saving lives on the railroads and highways.

Other Markets for NDGPS

Someday GPS/NDGPS receivers will be as common in cars as AM/FM radios are today. An integrated vehicle safety system consisting of a NDGPS receiver, collision sensors and communications links can help prevent accidents and notify emergency personnel when an accident does occur. A collision sensor, similar to the sensor in an air bag, could automatically send a preformatted message over a cell phone to an emergency response center at the instant an accident occurs. The message would contain the exact location of the accident from the NDGPS position. No longer will an injured person have to wait for a Good Samaritan to drive by the accident, locate a phone and call for help. The notification will be instantaneous. The emergency response team could use the NDGPS receiver to automatically plot the fastest route to the accident, taking into account the roads that are blocked by traffic. Thus, the notification time will be completely eliminated and the emergency response team's time will be greatly reduced. It is estimated that this could save up to three percent of the 41,000 people who die on U.S. highways each year, which amounts to 1,230 lives.

Similarly, a communications link from the emergency response center to cars equipped with NDGPS receivers could indicate where accidents have occurred. The NDGPS receiver could plot accident locations on an Electronic Graphic Display Unit and provide an audible warning to the driver as he approaches the accident. This warning of an accident a mile or two ahead could prevent multi-car pileups in poor visibility or icy conditions.

Many other Federal and state, public safety requirements have been identified. For example, NDGPS could be used in search and rescue, fire fighting, oil spill response, monitoring shipment of hazardous material, and mapping contaminated water supplies. In fact, many of these functions are currently being performed using DGPS in areas covered by the Coast Guard's system.

In addition to the public safety applications, NDGPS will be used in a myriad of other applications including weather forecasting, precision farming, and surveying. The National Oceanic and Atmospheric Administration will use the reference stations of the NDGPS system to improve the Nation's weather models. The GPS satellites broadcast signals on two frequencies. These signals are delayed at different rates as they travel through the water vapor in the atmosphere. The more water the more the delay. The amount of water vapor in the atmosphere can be very accurately predicted by measuring the difference in delay between these two frequencies. This continuous, real-time water vapor information from all of the NDGPS reference stations will be fed into the Nation's weather models, improving the short term weather forecasts.

In areas where the Coast Guard system provides coverage, farmers are using the signal to measure crop yields, apply only needed fertilizers and pesticides, and sample soil conditions. These applications are collectively known as "precision farming." Using NDGPS in precision farming increases crop yields and reduces pesticide and fertilizer use. The increase in yield increases the farmers' profits. The reduction in pesticides and fertilizers not only saves the farmer money but it also reduces the run-off of these chemicals into the environment.

Proof of Concept for GWEN Conversion

Since DOT's plan is to reuse the Air Force's GWEN sites, as they are decommissioned, FRA asked the Air Force if a site could be removed from the network to convert it into an DGPS site as a proof of concept. The GWEN site in Appleton, Washington, was converted and turned in May 1997. This first DGPS site has been transmitting flawlessly since then. Moreover, the efficiency of the 300 foot, reused GWEN antenna far exceeded initial expectations.

While a typical Coast Guard DGPS antenna is between 13 and 17 percent efficient, it was anticipated that the larger GWEN antenna would have an efficiency of about 35 percent. But the near perfect match between the antenna and the DGPS frequency resulted in an exceptional 51 percent efficiency. This means, that instead of radiating 130 to 170 watts, which is the power delivered by a typical Coast Guard antenna, the converted GWEN antenna pushes out 510 watts. The range of the Appleton site is 200 to 250 miles, depending on the terrain and ground conductivity. The Appleton site has also been used as a proof of concept for the use of DGPS in the Positive Train Control system.

Completing DGPS

The Department of Transportation and Related Agencies Appropriation Act, FY 1998, Public Law 105-66, Section 346 outlines the requirements and establishes the authority for DGPS. A copy of section 346 is attached. The law also provides $2.4 million, in fiscal year 1998, to begin the installation of the system. The FY 1999 Act continues funding, with an additional $7.5 million available for deployment of the system.

In addition to the accuracy of 1 to 3 meters and the integrity, time to alarm of 2.5 to 5 seconds, the DGPS will provide dual coverage nationwide. That means, anywhere in the country, corrections will be available from at least two reference stations. Thus, if an unusual occurrence eliminates the signal from one reference station, such as a lightening strike at one of the reference station or radio interference that jams one reference station, the other reference station will ensure continuous service. The percent of time that a service is available is referred to as operational availability. Since a single reference station is design to provides an operational availability of 99.7 percent, dual coverage will provide an availability of 99.999 percent.

The DGPS system will be installed using commercial products and services and will be maintained through commercial services contracts. Thus, the DGPS program maximizes the use of commercial products and services.

As mentioned earlier, the NDGPS will reuse Ground Wave Emergency Network (GWEN) sites which the Air Force no longer needs. The Air Force has 53 operational sites and 6 spare systems. The program will reuse the 300 foot antennas, two equipment shelters and a 25KW generator at each site. Since the DGPS coverage model predictions that 66 sites will be required, it will be necessary to purchase some additional antennas, equipment shelters and generators or battery back units.

Unfortunately not all of the GWEN sites are where they are needed. Thus, some of the sites will be moved to new locations. The plan calls for 33 GWEN sites in their current locations, 26 moved GWEN sites and 7 new sites. The sites will be installed in two phases. The first phase will provide single coverage to the entire country. The second phase will provide dual coverage. Based

~~on current budget constraints, the program will take four to five years to complete, but the Committee is advised that acceleration of the program is feasible if user needs require it and funding is made available.~~

~~Use of the NDGPS in the Positive Train Control system and in Intelligent Transportation Systems will promote this U.S. government augmentation system as a standard in transportation systems. The format of the broadcast signal will also be fully compliant with both RTCM SC-104 and ITU-R M.823. These non-proprietary, international standards are now used in over 35 other countries, leading to a seamless international system. The broadcast of the NDGPS corrections will be free of direct user fees as required under Public Law 105-66, Section 346. This will further encourage acceptance of the standard. An additional benefit of using an open, internationally accepted standard, is that it creates a world market for GPS equipment manufacturers and creates lower equipment costs for users through economies of scale and competition. Thus, both the manufacturers and users benefit.~~

~~The NDGPS sites will be integrated into three Federal systems: the Coast Guard's DGPS system for continuous integrity monitoring and control, the National Geodetic Survey's Continuously Operated Reference Station (CORS) system for high accuracy (5 centimeter) positioning applications, and the National Oceanic and Atmospheric Administration's Integrated Precipitable Water Vapor System for real-time input of water vapor data into the national weather models. From a national security perspective, the system will be operated by government, and thus can be denied to enemies of the United States, if the need arises, which is required by Public Law 105-66, Section 346.~~

C: Radio Frequency Spectrum Requirements

The freight, and passenger railroads in North American have licenses from the Federal Communications Commission (and its counterpart in Canada, the ~~Ministry of ??)~~Department of Communications) in three major bands, 160 MHz (VHF), 450 MHz (UHF) and 900 MHz (UHF). The VHF band is used primarily for voice communications, including all dispatch communications with trains. The 450 band is used for EOTs and distributed power. The 900 Mhz band was secured for ATCS and is used primarily for code line and work order. The code line application provides for control and monitoring of switches and signals in traffic control territory.

There is uncertainty over whether or not the available spectrum is sufficient for nationwide implementation of PTC. At 900 Mhz the number of channels (6) is likely to make the use of this spectrum in major cities very difficult, without additional channels. The 450 bandwidth is already used for EOTs and distributed power and has the same number of channels as the 900 band. The majority of the available bandwidth is at 160 MHz, which is subject to regulatory action by the FCC, and is currently used for all railroad private analog voice communications, making its use in a digital nationwide PTC network problematical. Generally, analog voice systems use simplex operations (transmit and receive on the same channel) and digital data networks, like those proposed for PTC work best on duplex or half duplex systems (transmit and receive on different channels).

Currently the freight railroads are evaluating different means of increasing the channel throughput for the 900 Mhz channels, and evaluating new technology for voice plus data radios at 160 Mhz.

The Federal Communications Commission in a rulemaking dated April 17, 1997, made several changes to the private land mobile radio (PLMR) spectrum below 800 Mhz. These changes were made to "encourage more efficient use of the PLMR spectrum." The principal changes were to consolidate PLMR service groups and to require that new radios by date certain operate on narrower band channels.

The railroads retained the right to coordinate the radio spectrum it currently uses, but are affected by the narrowbanding. This FCC action offers both opportunity and difficulty. Opportunity in that refarming will allow the railroads to have more channels, can use trunked networks, and can restructure those channels to meet current and future communications demand. Difficulty in that refarming needs to be done correctly to avoid technical errors and costly solutions.

Early on in the refarming process, the communications officers of the major freight railroads realized that the railroads needed to be prepared to cope with refarming through direct involvement in the rulemaking process, and in the selection of technology for new radios required by the FCC actions. The involvement in the rulemaking process was very successful in that the railroad coordination role was retained, trunking was allowed, and a less prescriptive rechannelization approach allowed. Through the North American Railroad Radio Network (NARRN) Task Force the railroads selected the APCO 25 protocol for the new 160 MHz radios and developed a model rechannelization plan.

The rechannelization plan calls for 10 eight channel duplex, trunking blocks wrapped around a 52.5 KHz band, which could be used for simplex communications. The eight channels blocks would be co-located at base stations, and both the transmit and receive channel would be located at repeater sites, and be transmitting and receiving at the same time. The rechannelization plan will support current analog operations as well as the proposed new digital operations using APCO 25, implying a migration path from analog to digital equipment, where both systems are likely to be operating in close proximity. Given the close spacing of the blocks, and channels within a block, how well will the system perform?

As a result of the Federal Communications Commission's (FCC) radio spectrum realignment initiative, land mobile radio users must incorporate spectrally efficient, narrowband

technology into their land mobile networks or risk being relegated to a secondary, non-interfering, user status in their currently authorized primary frequency pools. The railroad industry has responded to this initiative by forming the North American Railroad Radio Network (NARRN), an ad-hoc industry committee dedicated to solving radio communications issues unique to the railroad industry. NARRN members serve in a voluntary and cooperative role and represent the telecommunications divisions of their respective railroads in North America. NARRN is currently considering how to best migrate the railroad industry's existing 160-MHz analog land mobile radio equipment to more modern, spectrally-efficient systems and is developing a strategy to accomplish this migration. (repetitive)

The Federal Railroad Administration wishes to ensure that adopting NARRN's recommendations will not detract from the current level of railroad operations efficiency or adversely affect public safety. The Institute for Telecommunication Sciences (ITS), the research and engineering arm of the U.S. Department of Commerce's National Telecommunications and Information Administration, has performed work related to these issues, and the applicable results are reported here.

The first benefit of the radio spectrum realignment initiative was the doubling of the number of radio channels in the VHF band, from 91 to 181. This was accomplished by halving the allowable transmission bandwidth of radios.

In regions with a high volume of radio communications traffic, an immediate doubling of available channels to serve these areas was not realized because the existing radio equipment, with its wider bandwidth, would "splatter" signals over into immediately adjacent narrowband channels. This is somewhat analogous to the interference one would experience when tuning a television set to channel 5 and observing the interference effect that a local television station transmitting on channel 4 has on channel 5 reception. Some degree of geographical separation is required between a base station operating on one of the original railroad channels and a base station operating on one of the newly created adjacent railroad channels, but the amount of geographical separation is much less than that required between base stations operating on the same channel, so there is an increase (albeit somewhat less than double) in the number of radio channels available to serve a geographic region.

To further improve railroad radio communications, the railroads have agreed go beyond the currently practiced "dedicated channel" approach whereby, for example, yard operations have their own specific radio channel. Utilizing a concept known as trunking, many more user groups can be served by sharing a finite number of radio channels, just like a finite number of telephone trunk lines between telephone central office switches are shared by large numbers of individual telephone customers.

Incorporating trunking strategies requires locating multiple base station radios at a single site. This requires that the base stations transmit on one frequency and receive on a different frequency (duplex operation). The reason for using duplex operation is to protect a receiver from being overloaded by a signal from a transmitter. If all the base station transmitter frequencies are grouped together, and all of the base station receiver frequencies are grouped together, then special filters known as duplexers can be used to protect the receivers from being overloaded by strong signals from one or more of the co-located transmitters.

The Association of Public Safety Communications Officials (APCO) developed a series of specifications for new radio equipment and systems. The series of standards are known as APCO Project 25, or simply P25. This new equipment is narrowband, uses digital modulation, and will support trunking, encryption, private call, group call, voice plus data, talk group precedence, and other important functions and features. P25 radios are backward-compatible with older-generation analog FM equipment, permitting a phased migration to infuse the new equipment into service.

Public safety users (police, fire, etc.) are adopting equipment conforming to the P25 standards. Adopting a single equipment standard across multiple user communities enhances interoperability between different agencies. Adoption of the P25 standard by the railroads could enhance the ability for railroads and public safety entities to interoperate with one another in safety-related situations.

ITS performed a series of measurements to relate the delivered audio quality of speech signals transmitted through P25-compliant radios to radio sensitivity, adjacent-channel rejection and co-channel rejection parameters. The measurements were performed with the radios operated in both P25-digital and conventional analog FM modes. From this data, a representative case study illustrating the improvement in radio coverage afforded by the P25 platform was performed. Figure 2 shows two radio coverage contours, one for P25 digital mode and one for conventional analog FM mode. The contours delineate the regions where it is predicted that the delivered audio quality of speech will be greater than some perceived level of intelligibility.

Figure 2. Representative terrain coverage contours comparing analog and digital modes, for equal speech intelligibility.

The hypothetical site is assumed to be the Brownson, Nebraska, microwave site. The assumed base station and portable handheld radio parameters are summarized in Figure 2's inset box. A 5-watt handheld portable analog FM radio, located at any point within the purple-shaded region, is predicted to provide a high quality intelligible voice signal to the Brownson base station. By contrast, a 5-watt handheld portable digital P25 radio,

located at any point within the green- or purple-shaded regions, is predicted to provide a signal with comparable or superior speech intelligibility. Figure 2 shows that P25 digital mode affords improvement in coverage over analog FM systems, for a given level of speech intelligibility. Existing analog base stations could be upgraded to incorporate P25 technology, without requiring that additional base station sites be constructed.

In summary, the FCC's spectrum realignment initiative is requiring that land mobile radio users incorporate spectrum-efficient techniques or else risk the loss of their primary user status within their current land mobile radio band. The railroads are addressing this issue, and recommend that the industry move to a P25 platform and incorporate trunking technologies. Doing so will increase communications capacity to support major new emerging requirements, such as PTC/PTS. Many issues related to these new requirements are not yet well defined, and the railroad industry is studying with intense scrutiny how to best meet the anticipated demand.

D. Commercial Viability of PTC

There are a number of issues that need to be considered both during and after the deployment of a PTC system. Interoperability, where the locomotives of one railroad will operate onto the property of another railroad with full PTC capabilities is one issue. Another issue is intraoperability, where unequipped trains may operate among equipped trains.

Interoperability

As defined by the RSAC Implementation Working Group interoperability is "the capability of PTC equipped trains, locomotives, or other on-track vehicles to operate safely on other railroads, while maintaining at least the minimum (or core) PTC functionalities. The intent of PTC interoperability includes the elimination of interline delay and standardization of operator interfaces."

At the moment there are several systems being supported by FRA to achieve positive train control/separation. These systems use radio frequencies to move positioning information and movement authorities between locomotives or maintenance-of-way forces and control centers. These systems will be interoperable if the information messages that they move have the same content, follow the same protocol, and move on the same frequencies. In this context, interoperability means that a locomotive can move among different systems, communicating with and being subject to control by, the host PTC system. Ideally, the handoff from one system to another should be transparent to the operator and automatic, so that no interruption in enforcement capability will occur. Historically, Amtrak has accomplished interoperability by equipping locomotives with hardware responsive to each of the with a switch operated by the engineer and onboard controls responsive to all] ACS/ATS/ATC systems over which Amtrak operates and providing a switch for the engineer to use to turn on the proper system for the track over which the train is operating.

Practically, interoperability is a major concern. Until 1993, the freight railroads' commitment to ATCS planning offered the greatest possible assurance that locomotives equipped with the new train control system would be interoperable.

Theoretically, any number of disparate systems can be made interoperable, but practically it is very difficult. Interoperability is affected by the following factors: cost, and penalty in terms of complexity and compromised reliability. In the Intelligent Transportation Systems program of the Department of Transportation, interoperability is being achieved through the development of a common architecture, rather than through the development of "translators" between systems with different architectures.

Some of the PTC systems under development should likewise be compatible and will require similar treatment for interoperability if they continue to mature individually. The goal is to find a commonality that will provide interoperability by the addition of a card (hardware) or software, or both, at minimal expense. This will require that the railroads as a body adopt a basic standard for PTC design throughout the industry.

Each PTC system has been designed using a portion of the ATCS specifications, which broadly cover requirements for operating in the railroad environment. The designer of each system followed the ATCS specifications only as they appeared to apply to the system under development. Thus, interoperability between the systems does not exist. One system was designed with proprietary features. Therefore, open architecture does not encompass all the systems.

In some ways, interoperability is a business issue — when railroads develop sufficient run through traffic to justify the expense of interoperable systems that avoid terminal delay in order to expedite the traffic profitably, interoperability will occur. In example, historically the Union Pacific and Chicago Northwestern each had systems that were not compatible. The UP uses a 4-aspect cab signal system that functions on coded track circuits supplemented by automatic trainstop. The CNW system is a 2-aspect train control system that

functions on non coded track circuits — when the track circuit is energized, the cab indicator displays Clear, when de-energized it displays Restricting and initiates a full service brake application. Because of the business benefits of running trains through Fremont, NE and avoiding the delays associated with going through Council Bluffs and Omaha, the railroads installed both systems on a dedicated fleet of locomotives which achieved interoperability on about 50 train movements daily.

FRA has worked closely with the AAR, railroads, and vendors involved in the development of these systems. As a result of FRA's efforts, the AAR formed the Implementers Interoperability Task Force, a subcommittee of the AAR's Railroad Operations Communications Strategy Task Force. The Task Force's work is finished and the Task Force has been terminated. The Task Force was composed of representatives from railroads, suppliers, project integrators, AAR and FRA. Its mission was to review minimum interoperability requirements of PTS, ITCS and PTC and to determine the requirements for resolving incompatibilities. The task force worked to define and document the systems' requirements using ATCS specifications and each system's requirements. However, the results of the group's work can best be described as conceptual. No set of specifications or agreed-upon procedures was adopted, and therefor no conclusion can be drawn about cost effectiveness.

It will be important to find a common ground of agreement as to how interoperability can be achieved. Before this level is reached, it is necessary to understand the components of the different systems and to identify elements in each system that would not allow a particular system to operate successfully within the other's territory. After this knowledge is acquired, what can be added, changed, or possibly deleted in each system can be identified to make interoperability possible. FRA and others are concerned that the AAR efforts to achieve interoperability maybe terminated before results are achieved. Yet Amtrak and the major freight railroads are considering large capital investments that will yield wider safety and business benefits only to the extent interoperability can be achieved. Clearly, this is an arena that warrants early action.

Intraoperability

Intraoperability is defined as seamless operations within one railroad. Any discussion of interoperability must include a discussion of intraoperability. It is necessary to determine which Operating Rules are appropriate to handle unequipped trains, roadway workers, and On Track Equipment, and to define strategies, and how those strategies impact deployment.

The following types of operations raise intraoperability issues including: unequipped foreign line locomotives and home road locomotives, on board system failures, communications failures, out of communications coverage, whether a part of the design or not, maintenance of way equipment, short line railroads using track rights, and leased locomotive units from third party leasing companies.

From an operating rules consideration, implementing a PTC system can be done in one of three (3) ways:

A PTC system of the stand alone type will not only augment the existing signal system but will absorb its functionality to the extent wayside signals may safely be removed. Safety computers at a central office, on the wayside and on board each locomotive will enforce the proper spacing of trains, all speeds and stop where a stop is required. Stand alone PTC systems will become the method of train operations.

PTC systems of the Enhanced Capabilities type will be so interconnected with the existing signal system that its functionalities will be extended to equipment on board each locomotive that will enforce all speed and stop requirements prescribed by both the PTC and signal systems. The existing method of train operations will not change.

PTC systems of the overlay type will provide for among other things, enforcement of all speed and stop requirements while utilizing the existing system as the primary method of train operations.

If any system fails, then the railroad must have sufficient operating rules and instructions that will insure a safe and complete operating transition from current operations.

Some of the systems could work in the background virtually unknown to the train crew. While this has advantages, it would be a significant disadvantage should the train crew rely on the system when it may not be functioning correctly. Everyone that is subject to the operation of system is notified of system in place and operative, including the train crew, train dispatchers, and Maintenance of Way employees.

PTC System may range in form from highly interactive to totally invisible to the locomotive engineer. The following areas will need to be addressed to integrate PTC into the railroad.

The operation of equipped and non-equipped trains and how the joint operation is handled., and incorporating maintenance of way protection

Training for employees in the procedures to activate/deactivate the system, as well as recovering the system if an enforcement occurs.

Training for employees on procedures to take when the system fails

When the PTC system functions inappropriately and should be considered failed and deactivated and who needs to be notified.

Training for employees in the likely failure modes and how those failure modes may be displayed, or the appearance of a display failure.

Notification to train crews and maintenance of way forces of areas where PTC is not operational

Processes for initializing and terminating a PTC equipped train.

Procedures to handle PTC information updates that modify or conflict with the existing authority (e.g. detector activation, crossing malfunction, intrusion).

Existing method of operation rules would apply in failure of any system.

~~In order for PTC to be viable for revenue service in the real world, the system must be demonstrated to operate reliably and to be maintainable. A number of high-technology systems that worked in a laboratory environment, or in a limited deployment scenario, did not prove to be viable in daily operation in the rigorous railroad environment. The railroad environment is as difficult as any military operating environment in terms of the physical aspects of temperature extremes, exposure to weather, shock, vibration, electromagnetic interference, and handling in a rugged industrial workplace. The majority of PTC equipment will be installed in non-controlled environments on locomotives and along the wayside, which is not only harsh, but makes maintenance activities difficult. PTC equipment will be installed in widely geographically dispersed locations, in enclosures that are often difficult to perform maintenance due to space limitations, accessibility, and weather exposure. In addition to the hardware portion of PTC, there will be complex software and data to be maintained. Recent experiences with military and air traffic control software have demonstrated that software maintenance presents a challenge that industry is just beginning to cope with. PTC will also require data that must be accurate to ensure safety, and there are no existing processes in the railroad industry to ensure data quality for safety applications of the magnitude or impact of PTC. The technologies that constitute PTC must also be practical for deployment in terms of the ability of the work force to understand them, operate them, and maintain them.~~

~~All of these factors represent a PTC deployment challenge. Systems that work in the lab must first be demonstrated to work in pilot installations in the field. These pilot systems must then be shown to have the characteristics necessary to survive in the railroad operating and maintenance environment. Experience from these initial systems must then be reflected in PTC standards and specifications to provide the basis for procuring and deploying systems that will provide safety in wider-scale installations.~~

~~Deployment Issues~~

~~There are a number of issues that need to be considered both during and after the deployment of a PTC system. Interoperability, where the locomotives of one railroad will operate onto the property of another railroad with full PTC capabilities is one issue. Another issue is intraoperability, where there are unequipped trains operating among equipped trains.~~

~~Interoperability~~

~~As defined by the RSAC Implementation Working Group interoperability is "the capability of PTC equipped trains, locomotives, or other on-track vehicles to operate safely on other railroads, while maintaining at least the minimum (or core) PTC functionalities. The intent of PTC interoperability includes the elimination of interline delay and standardization of operator interfaces."~~

At the moment there are three systems being supported by FRA to achieve positive train control. These systems all use radio communications as the backbone of systems to locate and control speeds of trains to achieve safe train separation. Assuming that no single system emerges as being superior to the others, these and future PTC systems should be interoperable. In this context, interoperability means that a locomotive can move among different systems, communicating with and being subject to control by, the host PTC system. Ideally, the handoff from one system to another should be transparent to the operator and automatic, so that no interruption in enforcement capability will occur. Historically, Amtrak has accomplished interoperability with a switch operated by the engineer and onboard controls responsive to all ACS/ATS/ATC systems over which Amtrak operates.

Practically, interoperability is a major concern. Until 1993, the freight railroads' commitment to ATCS planning offered the greatest possible assurance that locomotives equipped with the new train control system would be interoperable. Fortunately, interoperability has been a major objective of some of the more recent technology development efforts.

Ultimately, any number of disparate systems can be made interoperable. However, interoperability is affected by the *cost, complexity and reliability.*

In some ways, interoperability is a business issue — when railroads develop sufficient run through traffic to justify the expense of interoperable systems that avoid terminal delay in order to expedite the traffic profitably, interoperability will occur. In example, historically the Union Pacific and Chicago Northwestern each had systems that were not compatible. The UP used a 4-aspect cab signal system functioned on coded track circuits supplemented by automatic trainstop. The CNW system was a 2-aspect train control system that functioned on non coded track circuits — when the track circuit is energized, the cab indicator displays Clear, when de-energized it displays Restricting and initiates a full service brake application. Because of the business benefits of running trains through Fremont, NE and avoiding the delays associated with going through Council Bluffs and Omaha, the railroads installed both systems on a dedicated fleet of locomotives which achieved interoperability or about 50 train movements daily.

Some of the PTC systems under development are likewise incompatible and will require similar treatment for interoperability if they continue to mature individually. The goal is to find a commonality that will provide interoperability by the addition of a card (hardware) or software, or both, at minimal expense. This will require that the railroads as a body adopt a basic standard for PTC design throughout the industry.

Each PTC system has been designed using a portion of the ATCS specifications, which broadly cover requirements for operating in the railroad environment. The designer of each system followed the ATCS specifications only as they appeared to apply to the system under development. Thus, interoperability between the systems is incomplete.

FRA has worked closely with the AAR, railroads, and vendors involved in the development of these systems. As a result of FRA's efforts, the AAR formed the Implementers Interoperability Task Force, a subcommittee of the AAR's Railroad Operations Communications Strategy Task Force. The Task Force's work is finished and the Task Force has been terminated. The Task Force was composed of representatives from railroads, suppliers, project integrators, AAR and FRA. Its mission was to review minimum interoperability requirements of PTS, ITCS and PTC and to determine the requirements for resolving incompatibilities. The task force worked to define and document the systems' requirements using ATCS specifications and each system's requirements. The ATCS specifications will provide for interoperability, but ATCS has not proven to be cost-effective.

It will be important to find a common ground of agreement as to how interoperability can be achieved. Before this level is reached, it is necessary to understand the components of the different systems and to identify elements in each system that would not allow a particular system to operate successfully within the other's territory. After this knowledge is acquired, what can be added, changed, or possibly deleted in each system can be identified to make interoperability possible.

Amtrak and the major freight railroads are considering large capital investments that will yield wider safety and business benefits only to the extent interoperability can be achieved. Clearly, this is an arena that warrants early action.

Intraoperability

Intraoperability is defined as seamless operations within one railroad. Any discussion of interoperability must include a discussion of intraoperability. It is necessary to determine which Operating Rules are appropriate to handle unequipped trains, roadway workers, and On Track Equipment, and to define strategies, and how those strategies impact deployment.

The following types of operations raise intraoperability issues including: unequipped foreign line locomotives and home road locomotives, on board system failures, communications failures, out of communications coverage, whether a part of the design or not, maintenance of way equipment, short line railroads using track rights, and leased locomotive

units from third party leasing companies.

From an operating rules consideration, implementing a PTC system can be done in one of three (3) ways:

Pure Overlay system. A pure overlay independent system PTC is installed on top of an existing train control or signal system. In an overlay system the control of the train is still under the jurisdiction of the dispatcher, and can be apparent or transparent to the operator, then the current operating rules will continue to apply.

Overlay with Enhanced Capabilities. An integrated - PTC System that adds additional safety critical functions, but retains the existing train control or signal system. This will use the existing code of operating rules to make decisions on train movements, but will require additions to those rules.

Stand-Alone system. PTC is the only method of operation, such system will likely be used by the Alaska Railroad. With a stand alone system new operating rules would have to be drafted

If any system fails, then the railroad must have sufficient operating rules and instructions that will insure a safe and complete operating transition from current operations.

Some of the systems could work in the background virtually unknown to the train crew. While this has advantages, it would be a significant disadvantage should the train crew rely on the system when it may not be functioning correctly. Everyone that is subject to the operation of system is notified of system in place and operative, including the train crew, train dispatchers, and Maintenance of Way employees.

PTC System may range in form from highly interactive to totally invisible to the locomotive engineer. The following areas will need to be addressed to integrate PTC into the railroad.

The operation of equipped and non-equipped trains and how the joint operation is handled.

Training for train crews in the procedures to activate/deactivate the system, as well as recovering the system if an enforcement occurs.

Training for crews on procedures to take when the system fails

When the PTC system functions inappropriately and should be considered failed and deactivated and who needs to be notified.

Training for crews in the likely failure modes and how those failure modes may be displayed, or the appearance of a display failure.

Notification to train crews and maintenance of way forces of areas where PTC is not operational

Processes for initializing and terminating a PTC equipped train.

Procedures to handle PTC information updates that modify or conflict with the existing authority (e.g. detector activation, crossing malfunction, intrusion).

Existing method of operation rules would apply in failure of any system.

E. Program elements models and simulation tools

Development of PTC will include a number of program elements to ensure that PTC products from suppliers are safe, cost-effective, interoperable, and maintainable in the railroad environment. The PTC Railroad Safety Advisory Committee (RSAC),RSAC, which includes the participation of railroads, the FRA, labor, suppliers, and other interested parties, is addressing PTC safety standards and functional requirements.

Elements of a PTC development program may include the following, which are to be used on the joint FRA/IDOT/Industry PTC Program:

Development of Standards and Specifications – A Systems Engineering (SE) Contractor has been competitively selected to support development of the standards and specifications for PTC. The SE contractor is working with the industry to define standards for PTC functionality, interfaces, and performance. These standards will form the basis for development of bid documents to select a System Developer/Integrator (SDI) for implementation of PTC on the Illinois high-speed corridor from Mazonia to Springfield. The competitively-selected SDI contractor will define more detailed interoperability interface specifications for PTC, and will install PTC on the IDOT corridor. The PTC standards and specifications will be used in the procurement of interoperable PTC systems by individual railroads.

PTC Pilot Program – There have been and continue to be a number of pilot programs within the railroad industry to test alternative PTC system approaches and related technologies. The Illinois PTC pilot program is a joint endeavor of the railroads, the FRA, and Illinois DOT. The PTC standards being developed will be augmented with corridor-specific requirements to produce PTC specifications for the Illinois corridor. The pilot system developed and installed in response to these specifications will provide a test bed to prove the viability of PTC concepts and evaluate PTC technologies, and provide standards for interoperable PTC systems. The pilot system program will deploy an operational system for the test bed corridor.

Testing – The Illinois PTC pilot program will include extensive testing of system technologies, operating practices, and rules, as well as a determination of the viability of PTC for real-world installations. Data from this testing will support evaluation of PTC life-cycle costs and benefits, as well as PTC performance.

Models – The PTC development program will include development and application of computer-based models to evaluate system performance requirements, design tradeoffs, system costs and benefits, implementation options, and safety impacts.

Simulation Tools – The PTC development program will also include development of simulation tools. Some of these simulation tools will be used to validate PTC system operation. A PTC simulation tester(s) may be developed to determine compliance of PTC products with the standards. Other simulation tools may be used to evaluate the operational impact of PTC, such as the potential improvement in corridor capacity due to flexible block control.

The joint Positive Train Control Program has as one of its objectives to "provide for industry interoperability, and demonstrate safe operation of locomotives equipped with interoperable systems." This objective will enable equipped trains operating from different railroads to come onto a foreign railroad safely at track speed. To meet this objective the Program will consider:

Locomotive human-machine interfaces with a minimum set of standard features, to provide the necessary and expected information for safe operation.

Compatible communications interface(s) to/from and on board the locomotive.

Minimum acceptable content and format of data bases.

Minimum common set of messages between devices and objects (functions) on board the locomotive/track vehicles and off board controllers.

Another of the Program objectives is to "provide a cost effective design, in order to enhance prospects for deployment." A cost effective design will consider the use of commercial of the shelf (COTS) equipment made by different manufacturers.

To be successful the industry will require a set of minimum interoperable standards that are unambiguous so that equipment built to these standards will operate correctly and can be proven to operate correctly. The proof can be obtained through extensive field testing, through a combination of field and laboratory testing (simulation) or through simulation alone. Simulation testing is effective in that it can:

Be more thorough than field testing, by testing scenarios that are either too complex for field testing or too hazardous.

Provide for more cost effective evaluations.

There are two categories of simulation tools proposed for the PTC Program. The System Developer/Integrator will need to build a simulator to evaluate the design of the system to be installed in the IDOT test bed from Springfield to Mazonia. The simulator can also be used to evaluate production subsystems and components to assure these devices function properly and meet the specifications.

The second set of simulation tools is to provide a cost effective and consistent means for evaluation of various systems built to industry interoperability standards. This

evaluation will determine if the system/components under test will:

Communicate properly – the simulation tool will test communications interoperability, both wire and wireless. Wired communications will most likely be limited to the onboard data bus. Wireless communications will consist of communications from the onboard system to any designated interoperable device off board e.g. dispatch office. This onboard/offboard test capability will evaluate the wireless link only.

Respond correctly to messages - assure the correct response of onboard devices to messages from other onboard and off board devices.

Behave correctly - Control flow tester to assure industry that modifications to interoperability standards will do what is intended and not degrade or injure existing systems intended to be compatible. This simulation tool will determine if the correct (safe) outcomes result. Testing can include deliberate degradation of the system through removal of components, and fault injection.

The simulation tools are proposed as a way to evaluate systems/components that is less risky and costly than field testing. For instance, fault injection intended to see if two opposing trains will respond correctly is likely to introduce unacceptable risk in field testing. Field testing requires the use of locomotives, communications, and other systems that can be reduced to computers with software in the simulator. In addition, all the testing will be done off line.

Field testing is still recommended for proof of concept and operational evaluation, but most of the safety assurance and system performance evaluations could be done with the simulation tools at much lower cost.

~~VII. Other communications, command and control requirements for the 21st Century: potential role for PTC systems (RSAC Progress Report Group, Lindsey to provide white paper on core infrastructure platforms / gateways). This section to address all non-safety benefits.~~

~~A. Efficiency-related attributes of available architectures~~

~~Communications infrastructure~~

~~Potential interface with CAD / traffic planners~~

~~Flexible blocks~~

~~***Commentary: Need to look at GE-Harris report that addresses these features.***~~

~~***B. Implications for traffic, information and asset management, system capacity, service quality and profitability [including discussion of the extent to which the National rail system is capacity constrained or is expected to become so within the next 2 decades]***~~

~~***C.***~~

~~***D. Alternatives to PTC technologies***~~

~~**Part E. Other than Safety Benefits**~~

~~Executive Order 12866, *Regulatory Planning and Review*, states that "Federal agencies should promulgate only such regulations as are required by law, are necessary to interpret the law, or are made necessary by compelling public need, such as *material failures of private markets to protect or improve the health and safety of the public.*" As presented in Chapter 5, the safety benefits of PTC, i.e., the enforcement of speed limits and movement authorities that help to maintain safe train-to-train separation distances and ensure the safety of track work crews, are substantial. The FRA recognizes, however, that safety benefits alone would not cover the costs of universal PTC installation. (need footnote here from Savage study~~

to show that there is no market failure of the railroad industry relative to safety).

Safety is driving the FRA's efforts to accelerate PTC deployment, but the technology also offers economic benefits. Although private sector economic benefits can not be the basis for regulatory action, Executive Order 12866 states that, "in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits (including potential *economic*, environmental, public health and safety, and other advantages; distributive impacts; and equity)." Accordingly, when assessing regulatory actions to accelerate PTC deployment, private sector economic benefits are relevant.

The economic benefits of PTC, or the "business benefits," have been the subject of extensive analysis. The FRA's 1994 *Railroad Communications and Train Control* study made the following statements regarding the business benefits of PTC: 47

As reflected in this report, ATCS offers significant potential business benefits to railroads with pertinent needs not otherwise addressed through alternative technology. These include fuel savings, better utilization of track and equipment (such as work order reporting, locomotive health monitoring, and traffic control), reduced wear on track and equipment, on-board hot bearing detection, car/trip scheduling, more precise scheduling of employee deployment, reduced job stress for dispatchers, and better service for customers (such as more reliable schedules and decreased transit time). All of these potential benefits offer possibilities for additional cost savings and managerial efficiency through increased network intelligence and enhanced information flows. [p. 61]

In the long term, the development of an integrated and interoperable communications network, such as ATCS, which will produce safety benefits, is likely. Commercial needs are growing; high quality service is essential to market growth in many sectors as shippers increasingly demand precision with respect to both pick up and delivery schedules. The rapid increase in intermodal service using containers, trailers, and other intermodal options places a premium on higher average train speeds, which requires better use of plant capacity and increasingly competent signal systems (as reflected by continuing investments in new traffic control systems on high density routes). As service requirements become more demanding on railroad plant, equipment, and personnel, the business benefits of flexible, interoperable, communication based PTC should become more evident and more readily quantifiable. [p. 62]

Previous rail industry technological advances produced benefits that were also difficult to estimate; the benefits of dieselization far exceeded predictions. FRA believes that the benefits of a control communications system B or flexible networks capable of functioning as a single system B can be expected to exceed the modest expectations of those advocating individual subsystems. Investments in safety and efficiency can produce synergies that result in unexpectedly high returns. [p. 63]

As indicated previously, the application of PTC to all rail lines has not been shown to be cost-beneficial at present based on safety alone. Business advantages to the railroad industry from such universal implementation can be expected, but the specific extent and nature of such advantages will differ greatly, depending on the particular circumstances. [p. 63]

Railroads recognize the need to move in the direction of positive train control, but with limited exceptions, have not considered the necessary investments justified. For the near future at least, safety benefits will have to be accompanied by "business" benefits for PTC investments to make business sense for widespread application to freight lines. [p. 76]

A central communication-based approach to PTC remains the most likely path to safer train operations. In addition, that approach has the greatest chance of returning business benefits that can help pay for a portion of the communication infrastructure needed to support safety applications. Although the application of PTC on all rail lines would not be cost-beneficial at the present time based on accident avoidance, PTC is required for high speed rail

service and may be warranted on heavily traveled freight lines as well. Implementation of PTC that is interoperable will facilitate more widespread realization of safety and other benefits. [p. 76]

On some major freight corridors, downsized rail plants are now straining to handle increasing volumes of intermodal freight movements, as trucking companies and international brokers recognize the value of rail as part of the intermodal team. If freight capacity becomes a limiting factor, the ability of the railroad industry to relieve pressure on congested highways and to serve the Nation's environmental goals may be compromised. [p. 77]

Railroads themselves have sought to measure the economic benefits of PTC since they first formulated the concept. In 1991, the Transportation Research Board (TRB), the Association of American Railroads (AAR), and the Railway Progress Institute convened a symposium on Advanced Train Control Systems. In the foreword to the TRB record of the symposium proceedings, Howard Moody, the AAR's manager of Advanced Train Control Systems, stated the following:[48]

ATCS benefits are great, with high rates of return and with significant hard-dollar benefits such as fuel savings and improvement in locomotive reliability. However, there are also significant soft-dollar benefits such as improvements in quality of service. These soft-dollar benefits are difficult to justify, in part because they are difficult to measure. Another aspect of these systems is the potential to provide options for additional benefits from as yet unanticipated applications developed as railroad managers become familiar with the technology. ATCS should not and cannot be justified on one application alone or on the safety benefits alone, but on an overall strategy to build on the early commercial applications and then to pick up the options. With the technical and financial risk involved, most railroads will use this building block approach to ATCS.

ATCS will require sophisticated integration with operations and information management systems. This is a very important part of any implementation strategy. ATCS also offer the potential to transform the industry to open up new ways to compete. In other words, ATCS may provide a competitive advantage to the railroads.

Also in 1991, the Harvard Business School published a case study describing Burlington Northern Railroad's (BN's) efforts to develop and analyze PTC.[49] The case chronicles the history of the company's ARES (Advanced Railroad Electronics System) project, which included the testing and demonstration of a prototype PTC system developed by Rockwell on 250 miles of track in northern Minnesota. Excerpts from the case study relate the expectations of the ARES project staff:

ARES will allow BN to run a scheduled railroad with smaller staffs and more modest [capital] investments than current signaling systems. It will maintain accurate, timely information about train consists and locations. The results will be improved service, with higher revenue potential, and cost reductions. Another important benefit will be the elimination of train accidents caused by violations of movement authority.

The potential benefit of ARES is large but highly uncertain: Using the best information currently available, we estimated the gross benefit in the range of $400 million to $900 million, with an expected present value of about $600 million. This benefit should be weighed against a cost of approximately $220 million (present value). The benefits depend greatly on implementation success: The system design must be sound, a strong implementation plan must be developed, and functional groups across the BN system must be committed to using it to full advantage.

The case presented a summary of the primary benefits expected from ARES:

Increased rail operations safety results from constant monitoring of wayside signal and detector equipment.

Greater operating efficiency and improved customer service come from operating trains to schedule and handling trains that deviate from schedule, the results of improved traffic planning.

Improved safety and increased customer service come from real-time position, speed and ETAs for all trains computed continuously and automatically provided to MOW crews and other BN users through existing BN computer systems.

Improved dispatcher productivity results from automating routine dispatching activities such as threat monitoring, warrant generation, traffic planning, and train sheet documentation.

Higher effective line capacity is provided by accurate vehicle position information and automatic train movement authorization.

Improved MOW productivity results from improved traffic planning.

Improved business management is possible with accurate, current information about the status and performance of operations and equipment.

The study examined benefits in the following areas and estimates the present value of those benefits:

- fuel $52 million
- equipment $81 million
- labor $190 million
- trackside equipment and damage prevention $96 million
- enhanced revenues $199 million

TOTAL $618 million

To account for uncertainty in these estimates, the study calculated ranges of values for them and probabilities of achieving values within the ranges

The factors with the largest potential for delivering benefits are also the most uncertain:

- ARES' ability to improve transit time and
- The amount customers are willing to pay for better service.

Accounting for ranges and probabilities, ARES will make the following mean contribution to net present value for each corporate strategy:

- focused strategy $360 million
- base strategy $406 million
- expansion strategy $576 million

The probability of ARES earning less than 9% real after-tax rate of return is extremely small

Ultimately, issues surrounding the company's overall financial operations and restructuring resulted in Burlington Northern's decision in 1992 to not implement ARES.

In 1993, the TRB, the AAR, and the FRA co-sponsored a conference on Railroad Freight Transportation Research Needs. At that conference, Moody discussed the state of ATCS development in the railroad industry and summarized the business cases developed by the Canadian National and Burlington Northern Railroads:.50

C3&I [Command, Control, Communication and Information] systems are being implemented to improve railroad productivity, customer service, and service reliability. Although significant progress has been made, even greater progress is in store in the future as railroads take advantage of advanced computer and digital data communication technology.

Both the Canadian National and Burlington Northern Railroads have done extensive business cases for ATCS. The Association of American Railroads (AAR) recently updated those business cases and provided the resulting report to its members. Both business cases demonstrated good potential internal rates of return, about half achieved with hard dollar savings and half with soft dollar savings. The industry is currently examining the long-range case for ATCS, and the next steps to take.

ATCS train control is expected to provide the following benefits:

Reduced headways to allow for increased line capacity. Independent studies indicate that a 25% increase is possible
Improved service reliability. ATCS has the capability to allow railroad operations to recover from delays and to improve meets and passes
Fuel savings from train spacing
Improved safety of operations from the use of digital data communication of movement authorities and from the enforcement of movement authorities and speed limits
Reduction in track damage and derailments due to excessive speed and poor train handling
Improved equipment use
Reduced dispatcher workload from the use of digital authorities to replace voice authorities

Complementary systems include the following:

Car distribution
Yard and terminal management
Strategic traffic planner and service design plan
Automatic equipment identification
Motive power management
Crew calling
Wayside and vehicle-borne detectors
Grade-crossing health monitoring, and
Remote control of locomotives

A draft report prepared for the FRA in 1997 examined the costs and business benefits of PTC.[51] The report presented the results of a study to provide a preliminary estimate of the business benefits of PTC on short corridors. Following are excerpts from that study:

Five railroad corridors, representing a range of conditions, were selected for study of the business benefits that would accrue if PTC were applied in each corridor. Benefits were quantified in the following areas:

reduced yard and transit time from improved work order reporting

reduced maintenance hours and en-route failures from locomotive diagnostics

fuel savings

reduced cost from improved equipment utilization

higher revenue from improved customer service

Benefits due to improved equipment utilization and customer service accounted for approximately 45% of estimated benefits; benefits from fuel savings and locomotive diagnostics, another 47%; and the remaining 7% was due to work order reporting.

Benefits quantified in this study were enough to cover 40% to 90% of total capital and operating costs of PTC, depending on the corridor and on the assumption regarding the number of locomotives that must be equipped. It is likely that cost coverage would be considerably higher if longer corridors conforming more closely to major transportation markets were chosen for analysis and if other business benefits not quantified in this study were able to be quantified. This is true not only because of the additional benefits, but also because, as more PTC-equipped route miles are added, fewer additional locomotives need to be equipped per added mile.

Benefit-cost ratios range from 0.34 to 0.90 for the five corridors. Two corridors have B/C ratios of roughly 0.6, indicating that there are significant benefits present, although too low to warrant investment on a corridor stand-alone basis. It must be remembered that corridors are being evaluated in isolation, and that this is the most costly method of implementation.

At present, there are a number of major efforts underway to develop PTC systems. Burlington Northern Santa Fe (BNSF, the successor to BN) and Union Pacific (UP) conducted a joint test of Positive Train Separation system in Washington and Oregon. The system was developed by GE-Harris, a joint venture between General Electric Company and Harris Corporation. GE-Harris also won a contract to install PTC on the Alaska Railroad. Wabco (formerly Rockwell) is building a PTC system for CSX to test in South Carolina and Georgia, and Harmon Industries is testing an incremental version of PTC for Amtrak in Michigan. CSX and Norfolk Southern have a contract with Wabco to develop an interoperable on-board locomotive communications bus for PTC to be demonstrated in Virginia, Maryland, and Pennsylvania. Another effort, sponsored by the AAR, FRA, and the State of Illinois, got underway in the summer of 1998.

Besides preventing collisions, the current PTC development efforts of BNSF, UP, CSX, Amtrak, and the AAR are expected to achieve greater operating efficiencies. PTC is expected to generate fuel savings to the railroads by allowing them to improve operations and scheduling. PTC, by pinpointing train locations, would permit railroads to do better meet-pass planning, thereby avoiding traveling at higher than necessary speeds and unnecessary waiting. BNSF estimates that it could save $24 to $40 million per year in fuel costs by moving at more constant speeds rather than the current pattern of hurrying up and waiting.[52]

The operating efficiencies produced by PTC, by improving utilization of locomotives, could reduce the number of locomotives needed. UP averages 2,300 meets and passes a day. If the time required for these actions could be reduced by 5 minutes each, the railroad would realize substantial savings on crews and equipment. The company estimates that for every mile-per-hour rise in average speed, 200 fewer locomotives would be needed. At an average cost of almost $1.6 million per locomotive, a mile-per-hour increase in average speeds would save UP $320 million on locomotive costs alone.[53] By similar logic, the size of the existing railcar fleet could also be reduced as a result of the operating efficiencies produced by PTC.

Summary

The ability to be able to better track and control the location of trains via the more precise location information and data radio links available from a PTC-type train control system, if exploited to optimize network flows, can clearly increase overall railroad network system capacity. In a published paper, GE-Harris notes that "[p]rimary savings will come from two sources: an increase in network productivity and an increase in dispatcher productivity."[54] They state that in studies that utilized actual train data, application of PTC technology resulted in average speed increases of 15 to 35%. During these studies they included anomalies such as undesired emergency brake applications, and the average speed was used as a figure of merit due to its direct relationship to asset utilization. GE-Harris notes that these speed enhancements were realized even though the objective of the study was to minimize train operating cost rather than maximize average speed. Finally, the GE-Harris paper states that "[a]nalytical projects based on a broad range of studies indicate that 95% on time performance (± 15 minutes) can be achieved in most cases where the controlling schedule is derived from the movement planner and the traffic is being controlled by PTC."

A document produced by the BN ARES project team in August, 1991, addressed capacity enhancement. BN noted that considerable effort was put into modeling the way the railroad would operate with ARES in place and that the results of their studies indicated ARES could deliver 20% reduction in turn around times for unit trains, 15% improvement in on-time performance for freight trains, a 50% reduction in missed connections, and several years' delay in the need to add track capacity in bottleneck areas. BN goes on to note that it foresaw significant reductions in capital outlays for cars and locomotives and significant reductions in fuel consumption among other potential benefits of adoption of a control system with the attributes of ARES.[55]

Although the full impact of how a PTC installation will affect railroad operations is often debated the examples above show that detailed study of particular systems and potential installations clearly point to real and significant positive impacts on the railroad's operation. The benefits of a PTC system can be taken through decreases in overall shipment transit time, increases in reliability of transit delivery times, or through higher system throughput. How a railroad chooses to take these benefits, and in what combinations and ratios, will depend on their individual business plans, the types and mixes of freight hauled, and the type of service they wish to provide to their shippers. Nevertheless, the benefits from reduced transit times, increases in system average speeds, and more consistent and reliable service can be achieved and can be quantified on a case by case basis.

Another way to look at potential savings, or benefits, from PTC capacity enhancements is to consider the alternative costs of increasing capacity through the more traditional means of line upgrades or expansions. A UP press release dated December 1, 1998, cited a cost of $88 million for the construction of 32-mile stretch of track in western Iowa, or $2.75 million per mile to construct Class 5 track where a mainline had been removed in 1965.[56] Two other railroad line capacity upgrades in the last year cost $180 million for 108 route-miles ($880,000 per route-mile) and $ 220 million for 270 route-miles ($1.66 million per route mile).[57-58] These projects range from complete new mainlines on routes with preexisting high levels of signaling capabilities to sections of new mainlines on partially multi-tracked routes with less advanced signaling capabilities that needed to be augmented. Another point of reference is a cost of $568,000 per mile for construction of unsignalized yard track with 100 pounds-per-yard rail.[59] Clearly, adding capacity to railroads is not inexpensive. The UP notes that for their central corridor alone they plan to spend $856 million to expand capacity over the next five years.[60]

Although physical upgrades and additions of another track offer significant capacity improvements, PTC can help squeeze additional capacity out of existing lines before the need for a step function increase in capacity is reached. Capacity improvement projects often include not just track additions but improvements to signaling systems, such as installing bi-directional signaling to single direction signaling. PTC installed on such a line will also be able to gain the same capacity improvement benefit without any added costs. PTC's contribution to line capacity improvement can range from significant for a poorly-dispatched single-track unsignalized line to probably only a few percent for a well-dispatched double-tracked bi-directional CTC-signaled line.

Numerous studies have addressed the business benefits of PTC and identified positive effects accruing to the railroad industry. Although it is difficult to

~~accurately predict the full extent of the benefits, they appear to be substantial. As hardware and software costs continue to decline and railroad traffic continues to grow, the magnitude of the benefits should become even greater.~~

~~In spite of the vast number of studies outlining the potential business benefits of PTC and its predecessors, no large scale implementation has occurred, because there as yet has not been sufficent justification to make the investment. Studies, after all, are just studies.~~

~~F. Achieve scale of implementation necessary to return benefits~~

Appendices:

Glossary [start with terms from 1994 report, Sec. 17 AAR S&TC, other sources as appropriate]

Final Report: Corridor Risk Analysis Model [Include summary of views regarding usefulness of results.]

Compendium of Current Positive Train Control Project.

NDGPS Enabling Legislation

[1] Eno Foundation, "Transportation In America: 1998," p.44.
[2] Association of American Railroads, "Railroad Facts: 1998 Edition (1997 data)," p. 28, 44
[3] Ibid, page 27
[4] Association of American Railroads, "Analysis of Class I Railroads: 1997," p. 24.

[5] Association of American Railroads "Weekly Railroad Traffic"
[6] Memo to 1993 Commodity Flow Survey data users on shipments of hazardous materials, Table 1.
[7] STB "1996 Carload Waybill Sample" processed by FRA.
[8] STB, "1996 Carload Waybill Sample" processed by FRA.
[9] U.S. Department of Agriculture, "Transportation of U.S. Grains: A Modal Share Analysis, 1978-95," March 1998
[10] p. 23
[11] Standard and Poor's DRI "North American Transportation Quarterly," Third Quarter 1998, p. 18.
[12] STB "1996 Carload Waybill Sample" processed by FRA.
[13] Federal Highway Administration, "1997 Status of the Nation's Surface Transportation System: Condition and Performance, Report to Congress," Exh. 3-7, p.18.
[14] Standard and Poor's DRI "US Freight Transportation Forecast...to 2006," Fig. 9, p.10.
[15] National Highway Traffic Safety Administration, "Traffic Safety Facts 1996, " Table 3, p.17.

[16] Traffic World," Nov. 16, 1998, p.42.

[17] ~~Fiscal Year 1999 Report on Funding Levels and Allocations for Transit Major Investments; Federal Transit Administration May1, 1998~~
~~Fixed Guideway Inventory; American Public Transit Association, 1998~~
~~Commuter Rail: Serving America's Emerging Suburban/Urban Economy; American Public Transit Association; September, 1997~~

[18.] Fiscal Year 1999 Report on Funding Levels and Allocations for Transit Major Investments; Federal Transit Administration May1, 1998
[19] Fiscal Year 1999 Report on Funding Levles ad=nd Allocations for Transit Major Investments; Federal Transit Administration May 1, 1998
[20.] Fixed Guideway Inventory; American Public Transit Association, 1998
[21] Fixed Guideway Inventory; American Public Transit Association, 1998
[22.] Commuter Rail: Serving America's Emerging Suburban/Urban Economy; American Public Transit Association; September, 1997
[23] Commuter Rail: Serving America's Emerging Suburban/Urban Economy; American Public Transit Association; September, 1997
[24] William Carley, "Railroads Test Satellite Positioning in Effort to Improve Safety, Efficiency," Wall Street Journal Interactive Edition, June 29, 1998.

[25] Section 4, p.1.

[26] Section 4, p.1.

[27] *Source:* Annual Report 1997 Railroad Safety Statistics, This number includes train accidents (includes highway-rail crossing) and highway-rail incidents.

[28] Does not include categories o and w.

[29] *Since the Model relies on an empirical relationship between the accident rate and track and traffic data, it cannot predict the capability of any PTC system to reduce risk, nor can the Model determine the potential benefits of any risk reduction strategy such as modification of operating rules. Initially this effort was left to subject matter experts, but a more complete risk analysis approach is suggested using an Axiomatic Safety-Critical Assessment Process, outlind later in this report.*

[30] *The defined corridors are a subset of the GIS database, resulting in a smaller number of PPAs*

[31] Table 1 shows accident data for the years 1988 – 1997 inclusive. CRAM used data from 1988-1995 inclusive and "predicted" the 1996 and 1997 outcomes.

[32] "Partially" preventable means that PTC might help prevent the accident but there was considerable uncertainty that PTC could prevent that accident from occuring.

[33] *Railroad Communications and Train Control, Report to Congress.* U.S. Department of Transportation, Federal Railroad Administration, Office of Safety. July, 1994.

[34] Transportation Research Board, *Transportation Research Record No. 1314, Rail: Advanced Train Control Systems, Proceedings of a Symposium. June 17-19, 1991.*

[35] Hertenstein, J., and Kaplan, R., *Burlington Northern: The ARES Decision (A)* and *(B)*, Copyright 1991 by the President and Fellows of Harvard College. Harvard Business School Case numbers 9-191-122 and 123.

[36] Moody, H.G., A Command, Control, Communication, and Information Systems@, *Railroad Freight Transportation Research Needs*, Proceedings of a Conference, July 12-14, 1993. Washington, DC: National Academy Press, 1994.

[37] *An Examination of the Costs and Business Benefits of Positive Train Control (Draft)*, performed under contract to the Volpe National Transportation Systems Center by Parsons Brinckerhoff Quade & Douglas, Inc., and Zeta-Tech Associates, Inc. 1997.

[38] Carley, William, "To Avoid Collisions, Some Railroads Test Satellite Positioning", *Wall Street Journal*, June 29, 1998.

[39] Ibid.

[40] "Precision Train Control™ System", GE-Harris, white paper, undated.

[41] "ARES For Safety and Service", Burlington Northern Railroad, August, 1991.

[42] News Release, Omaha, December 1 - Union Pacific Commemorates Opening of Iowa Double-Track Main Line, Union Pacific Railroad Website www.uprr.com, December 9, 1998.

[43] News Release, Omaha, November 5 - Union Pacific Expands Freight Capacity in Iowa and Nebraska With Track Improvements, Union Pacific Railroad Website www.uprr.com, December 9, 1998.

[44] CSXT Press Release, Willow Creek, Ind., November 20, 1998 - Golden Spike Marks Completion of Major Rail Project, CSXT Website www.csxt.com . December 7, 1998.

[45] Building Construction Cost Data, R. S. Means, Inc., 1994 Edition. Page 56.

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[50] Moody, H.G., A Command, Control, Communication, and Information Systems@, *Railroad Freight Transportation Research Needs*, Proceedings of a Conference, July 12-14, 1993. Washington, DC: National Academy Press, 1994.

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